

*AN INVESTIGATION OF ACCESS CHEMISTRY  
LECTURERS' PRACTICE OF PEDAGOGIC CONTENT  
KNOWLEDGE IN CHEMICAL EQUILIBRIUM IN AN  
ACCESS PROGRAMME*

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*A research report submitted to the Faculty of Science, University of the  
Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree  
of Master of Science*

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## **CANDIDATE'S DECLARATION**

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

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## ABSTRACT

A qualitative case study was used to investigate the pedagogical content knowledge (PCK) in chemical equilibrium by two chemistry lecturers in an access programme at a technical university in Johannesburg. Since PCK has been identified as knowledge which is unique to teachers, the difference between the two lecturers' teaching background, made for an interesting comparison. Mr Dhlamini was a post-graduate student who could have been described as an expert in the field of chemistry as he was completing his doctorate in chemistry and Mr Moerane who was an experienced teacher. Interviews as well as observations of the lecturers' classroom practice were conducted to establish their interpretations and transformations of concepts in chemical equilibrium that make these concepts understandable to the student. The methodological tools used to document and portray the lecturers' PCK in chemical equilibrium, used representations called Content Representation (CoRe) and Pedagogical and Professional – experience Repertoires (PaP-eRs). The CoRe elaborated on the teacher's construction of content which framed the topic chemical equilibrium and each Pa-PeR, was a narrative derived from the interview before the lesson on chemical equilibrium was taught, the observation of two lessons, the lecturer's reflections after the lesson and stimulated recall sessions. The use of the two tools was modified to suit the context of the study. A tailored model of PCK developed by Rollnick *et al.* (2008) was used to analyse and interpret data. The study showed that Mr Moerane's PCK was far better developed (as shown by the overall strategy he developed and representations he used) while Mr Dhlamini, though a competent teacher, still had to develop a strategy, based on his understanding of practice.

To my family  
Thank you for your patience and support throughout this research  
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# **CHAPTER 1: INTRODUCTION**

## **1.1 INTRODUCTION**

In order to prepare the youth to take their place successfully in society, they go through various stages of education. At each stage they are exposed to teachers who have been trained at either universities or teacher training colleges. Irrespective of how they have acquired their teaching qualifications, teachers/lecturers need to be prepared to take up their role in teaching. The preparation of teachers at teacher training colleges involves a practical (pedagogical), education theory and content component. Lecturers at tertiary level do not have teacher training. The focus of teacher training therefore tends to be different to preparation of lecturers.

Teacher training for pre-service primary and secondary school tends to focus mainly on the development of pedagogical skills, while the deepening of content knowledge seems to be less important. At tertiary level, in contrast, it is assumed that content knowledge alone is sufficient to teach successfully. As a result, many lecturers at the university level have come through the system as students, then as tutors and finally take their place as lecturers without any pedagogical training in their content subject. However, this raises the issue of the various skills and content knowledge lecturers need to acquire and develop in order to be adequately prepared for teaching practice. Of interest, too, is the manner in which the knowledge and skills are utilized in the classroom, although specialists maintain that these skills are acquired and extended, and content knowledge deepened through teaching experience. Shulman (1986) described this specialised knowledge of the experienced, expert teacher as “Pedagogical Content Knowledge” (PCK) and as being unique to teachers. Teaching experience is thus a prerequisite to the development of PCK and subject matter knowledge (Van Driel *et al.*, 1998).

Lecturers at tertiary level are therefore generally well versed in their subject area, but have often had limited formal teacher training and as a result, manifest little pedagogical content knowledge. However, in certain circumstances one of the requirements for a lecturer to work in a particular programme is previous teaching experience. The teaching of Access Chemistry in the bridging programme at the former Technikon Witwatersrand (now known as the University of Johannesburg, Doornfontein campus) which takes place at the school university interface, but is located within the university context, is one such programme. Access courses are provided for promising students who are under-prepared for tertiary education and they support them in various key subjects through a bridging year before they take their place in mainstream degree and diploma courses.

## **1.2 STATEMENT OF THE PROBLEM**

As a moderator and facilitator (now known as senior subject coordinator) of Access Chemistry in the bridging programme in the Academic Support Unit (now known as the Academic Development Division) at the University of Johannesburg, the researcher has found that students find difficulty in grasping and understanding the many topics and concepts in chemistry. One of these topics is chemical equilibrium. Chemical equilibrium is rated as one of the most difficult concepts for students to comprehend (Banerjee, 1995; Wheeler and Kass, 1978) and one of the more difficult sections of physical science to teach (Bergquist and Heikkinen, 1990; Tyson, Treagust and Bucat, 1999), which is confirmed through research into misconceptions held by students and teachers of this topic.

There could be many reasons for this difficulty. However, the problem is aggravated when students' background knowledge, which is a prerequisite to understanding chemical equilibrium, is lacking. In order to address these problems related to the topic of chemical equilibrium, it was expected that the lecturers who taught access chemistry in the bridging programme, should not only have a sound knowledge of

chemical equilibrium, but also well-developed, content-specific pedagogical knowledge or PCK. PCK is a synthesis of subject matter knowledge and pedagogical knowledge that differentiates expert teachers in a subject area from subject area experts (Shulman, 1986). More importantly, it is also the content knowledge that promotes understanding in learners and is considered the specialty of the experienced teacher.

The presence of two lecturers, one a qualified teacher, and the other a subject matter expert, teaching in the access chemistry bridging programme at the Technikon Witwatersrand, offered an opportunity to study the differences in their pedagogic practice and in addition, to acquire information about and understanding of their PCK in the topic chemical equilibrium. One of the lecturers, Mr Dhlamini, was an expert in chemistry with no teacher training and limited teaching experience, thus it was reasonable to assume that he might not at that time have developed the required PCK to address the problems manifested by the bridging students on this particular topic of chemistry. In contrast, the other lecturer, Mr Moerane, had undergone teacher training and had considerable teaching experience in chemistry, but less content knowledge. Thus, an investigation of the classroom practice of these two lecturers was a logical area of study.

### **1.3 AIM AND RESEARCH QUESTIONS**

The aim of the study was to find out how the two lecturers transform their subject matter knowledge in chemical equilibrium, and adapt their pedagogy in order to make this difficult topic comprehensible for the students.

In particular the following research questions will be explored in this study:

1. What is the PCK of the two lecturers with respect to teaching the topic chemical equilibrium?



2. What differences exist between the two lecturers' PCK with respect to chemical equilibrium?
3. How can we capture and portray the lecturers' PCK with respect to chemical equilibrium?

## **1.4 IMPORTANCE OF THE STUDY**

According to Geddis and Wood (1997), a variety of studies of different aspects of teacher education had been done. However at the time only a few detailed case studies of the practice of teacher educators and hence few studies which focussed on the PCK of teachers were amongst these. Research on PCK highlights the lack of attention to the management of ideas in teaching (Geddis and Wood, 1997). As a result, this particular study is important as it shows not only the management of ideas by two lecturers when teaching the topic of chemical equilibrium, but also shows a way of capturing and portraying the ideas, using a modified model of CoRe and PaP-eRs (Loughran *et al.*, 2003 and 2004) which will be expanded on and discussed in chapter 2. It also makes the two lecturers' tacit knowledge more explicit. It could then serve as a resource for teachers and researchers alike for the topic, chemical equilibrium. Teachers could use this modified model as a framework to inform their teaching of this topic, as the CoRe focuses on the concepts which frame the topic and the PaP-eRs focus on the teaching practice.

## **1.5 RATIONALE FOR THE STUDY**

It has been stated that many students have difficulty with understanding certain concepts in chemical equilibrium which is evident in their performance in assessments. Possible reasons for the difficulty with understanding could be the way in which learning and teaching happens or with students' existing misconceptions. There has been extensive research carried out on misconceptions on various topics in

chemistry, including chemical equilibrium (e.g. Quilez-Pardo and Solaz-Portoles, 1995; Vilakazi, 1990; Hackling and Garnett, 1985). An investigation into the subject matter knowledge for teaching this topic is therefore a logical area of study to acquire information about the reasons for students' difficulty.

## **1.6 RESEARCH METHOD AND DESIGN**

A qualitative approach involving audiotaped interviews and videotaped observations, with a case study research design, was used to investigate the teaching practice of the two chemistry lecturers in an access programme at the then Technikon Witwatersrand. Mr Dhlamini was completing a PhD in Catalysis, and had been a postgraduate tutor to undergraduates at another university. Mr Moerane had a teaching qualification and had taught chemistry at senior secondary level for seven years. At the time of the study, he had been teaching chemistry in the access chemistry programme for only three months.

Data was collected using researcher's field notes from complete observations in which the lecturers' practice was observed without participating in the activities (Fraenkel and Wallen, 1996), from one-on-one interviews and from stimulated recall sessions and reflections. Lecturers' classroom practice was observed to find out about their interpretations and transformations of concepts in chemical equilibrium that make these concepts understandable to the student. The researcher observed two groups per lecturer on two occasions while they were teaching this particular topic. Interviews were also conducted with both lecturers. Interviews took place before and after the classroom observations. The pre-interview was to gather data on how each lecturer prepared for the classes and what was considered important. The post-interview was short, purely for clarification of issues observed in the lecture. The gathered data was then used to develop a CoRe and PaP-eRs, which were modified from Loughran *et al.* (2003). A tailored model of PCK which was developed by

Rollnick *et al.* (2008) which will also be discussed in more detail in chapter 2, was used to interpret the data.

The validity and reliability of the research study was enhanced by the triangulation of data by using interviews and observations to collect the data and then by videotaping the lessons and audiotaping the interviews. Data was validated by both researcher and the participants, who had been observed. The ethics of the study was considered, as the researcher sought permission from the University of Johannesburg, the lecturers who formed part of the sample, and the students who participated in the lesson. Agreement forms were signed by all parties involved.

Chapter 2 outlines the theoretical framework of the study and the relevant literature is reviewed and discussed. Chapter 3 outlines the research design and the methodology is described. In chapter 4 the PaP-eRs and the developed CoRe of Mr Moerane and Mr Dhlamini are discussed. In chapter 5, the results are discussed. Chapter 6 discusses the findings, concludes the study, outlines weaknesses of the study and offers recommendations.

## **1.7 CONCLUSION**

The above discussion of the various aspects of this research study will be framed by the research literature and the theoretical framework which will be outlined in the next chapter.

## **CHAPTER 2: LITERATURE REVIEW AND THEORETICAL FRAMEWORK**

### **2.1 INTRODUCTION**

In this chapter studies, which focus on the following aspects of PCK and chemical equilibrium will be reviewed:

- The construct of PCK;
- Difficult concepts to teach and learn in chemical equilibrium;
- Content-specific PCK with respect to concepts in chemical equilibrium;
- Using models to capture, document and portray PCK;
- Identification of models which can be used for data analysis with respect to PCK.

There are very few studies, which have reported, documented and portrayed PCK in the topic chemical equilibrium, the study of Van Driel *et al.* (1998; 2002) being the exception. Most of the other studies have focused on learners' and teachers' alternative ideas and conceptions on chemical equilibrium and issues related to teaching chemical equilibrium (e.g. Quilez-Pardo and Solaz-Portoles, 1995; Vilakazi, 1990; Hackling and Garnett, 1985). With the knowledge and awareness acquired from this research, and new developments in science education, we need to be investigating strategies that could improve the learning and teaching of difficult topics such as chemical equilibrium. Another idea for consideration is that although there has been much discussion about PCK, how does one acquire or develop one's PCK in particular topics in science?

## 2.2 WHAT IS PEDAGOGICAL CONTENT KNOWLEDGE?

The term *pedagogical content knowledge* (PCK) surfaced for the first time in Lee Shulman's presidential address at the 1985 annual meeting of the American Educational Research Association, Chicago. Schulman characterized PCK as:

*"...a particular form of content knowledge that embodies the aspects most germane to its teachability. This includes the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that makes it comprehensible to pupils..."*. (1986: p9)

Shulman (1987) portrays PCK as a fixed body of knowledge whereas Cochran *et al.* (1993) propose a modified construct of PCK from a constructivist perspective which focuses on the dynamic nature of PCK. They describe it as pedagogical content knowing (PCKg) as it is constantly being developed with experience. Pedagogical content knowing is defined by Cochran *et al.* as:

*"...a teacher's integrated understanding of four components of pedagogy, subject matter content, students characteristics, and the environmental context of learning..."* (1993: p267).

Since the emphasis is on the development of pedagogic content knowing within a certain context, the student's prior knowledge and the context of the student is of extreme importance. In this study the context of the student is also highlighted. Students have been placed in an Access Programme and therefore the lecturer's pedagogical content knowledge is important in developing the student's conceptual understanding in chemistry.

There are several different interpretations of PCK which exist. An analysis of the interviews by Marks resulted in a conception of pedagogical content knowledge consisting of four components:

*“... subject matter for instructional purposes, student understanding of the subject matter, media for instruction in the subject matter and instructional processes for the subject matter” (1993: p4 ).*

Geddis and Wood (1997) construe pedagogical content knowledge, similar to that of Marks (1993), as a broad category of those kinds of knowledge involved in pedagogical transformations of subject matter, which include:

*“Knowledge of a range of subject matter representations, learners’ typical preconceptions, especially effective instructional strategies, available curriculum materials, and the curricular saliency of this particular subject matter for the curriculum as a whole. All these can be seen as amalgams of subject matter and pedagogical knowledge” (Geddis and Wood, 1997: p 612).*

Reynolds (1992) does not explicitly mention the term PCK but suggests that good teachers need to develop the following four attributes, which to the researcher implies PCK:

- *Knowledge of the subject matter they will teach;*
- *Knowledge of strategies , techniques and tools for creating and sustaining a learning community, and the skills and abilities to employ these strategies, techniques and tools;*
- *Knowledge of pedagogy appropriate for the content area they will teach;*
- *The disposition to reflect on their own actions and students’ responses in order to improve their teaching and the strategies and tools for doing so.*

According to Grossman (1990), PCK is derived from certain domains of teacher knowledge such as subject matter knowledge, pedagogical knowledge and knowledge of context. In her discussion, she further describes PCK as comprising various components such as knowledge of overarching conceptions of teaching, knowledge of students’ understandings, curricular knowledge and knowledge of instructional strategies.

Borko *et al.* define PCK as:

*“... knowledge of subject matter for teaching ... [that] consists of an understanding of how to represent specific subject matter topics and issues in ways that are appropriate to the diverse abilities and interests of learners”*(1992: p50).

In this study PCK will be described according Rollnick *et al.*, 2008, as:

*“... how teachers engage in the business of teaching their subject by accessing what they know about their subject, the learners they are teaching, the curriculum with which they are working and what they believe counts as good teaching in the context of the situation in which they are operating”*(Rollnick *et al.* 2008:p5)

Most research on PCK has been carried out with elementary student teachers (pre-service teachers) (Ball *et al.*, 2004; Van Driel, 2002; Enfield, 2000) novice teachers (e.g. Freitas *et al.* 2004; Geddis and Wood, 1997; Shulman, 1987; Marks, 1993) and experienced teachers (e.g. Ball *et al.*, 2004; Van Driel *et al.* 1998; Geddis and Wood, 1997; Chen and Ennis, 1995; Marks, 1993; Shulman, 1987). However, in most of these studies, as in this study, the more experienced teacher is used as a comparison for the novice teacher (Ball *et al.*, 2004; Geddis and Wood, 1997, Shulman, 1987, Marks, 1993). These studies expose and highlight the complex bodies of knowledge and skill needed to function effectively as a teacher which is displayed with ease by the experienced teacher (Shulman, 1987).

The researcher found few studies which focus on the PCK of the subject expert. Although teaching experience can be conceptualised very differently from one context to another, there seems to be a certain amount of consensus amongst science education specialists about the importance of teaching experience. Chen and Ennis (1995) studied experienced teachers whose experience ranged from 14 to 32 years and Geddis and Wood (1997), in their case study on vignettes of teachers included an experienced teacher with 30 years teaching experience. The experienced teacher in

the current study had 9 years teaching experience when the data was collected. Therefore, in this study, the experienced teacher has been conceptualised in terms of (i) an extended length of time as a teacher, and (ii) a demonstrated interest in studying both the theory and craft of teacher education (Geddis and Wood, 1997) and the expert as an inexperienced teacher who has demonstrated an interest in only studying the subject content and not the theory and craft of teacher education.

Chen and Ennis (1995) findings indicated that the teachers shared a common subject content knowledge base but demonstrated a personalized PCK, suggesting that the teachers' PCK was personally constructed even though they shared a common subject content knowledge base. Furthermore, the classroom curriculum was closely connected to the pedagogical content knowledge base of the teacher. In addition, the teachers' curricular decisions regarding content inclusion/exclusion were primarily based on their perceptions of student learning abilities.

## **2.3 THEORETICAL FRAMEWORK**

A number of models have been derived from Shulman's model of PCK. Grossman's (1990) model suggests a reciprocal relationship between the base domains of teacher knowledge such as subject matter knowledge, pedagogical knowledge and knowledge of context, and PCK. Geddis and Wood (1997) present a model of "teaching as a transformation of subject matter". The transformation of subject matter is dependant on the types of knowledge listed earlier. According to this model, PCK is an amalgam of varied categories, including learners' prior concepts, subject matter representations, instructional strategies, curriculum materials and curricular saliency. Curricula saliency is a term coined by Geddis and Wood (1997) which describes the ability of a teacher to provide perspective on the dilemma of breadth versus depth of coverage of a particular topic within the curriculum. In their model, the teacher's individual understanding of the subject matter combined with the PCK gives rise to a transformation of the subject matter. However, very little is said about the influence



of teachers' actual subject matter knowledge understandings on PCK. According to Geddis and Wood (1997) their model can be used in teacher education.

Gess-Newsome's (1999a) model of PCK identified the three important areas, viz. conceptual knowledge, subject matter structure, and content-specific orientations to teaching. This model of PCK provides a useful framework especially in this study where the two lecturers' PCK is being compared. These three areas and the findings most germane to their study have been summarised in the following table by Rollnick *et al.* (2008):

Area	Relevant Findings
Conceptual Knowledge	<ul style="list-style-type: none"> <li>• Even well qualified novice teachers resort to reliance on algorithms, rules and text books</li> <li>• Reduced flexibility in teaching the subject</li> <li>• Teachers new to a topic may readjust their understanding after teaching a lesson</li> </ul>
Subject matter structure	<ul style="list-style-type: none"> <li>• Experienced teachers have coherently structured rich subject matter structures, allowing them to envision longer periods of instruction planning</li> </ul>
Content specific Orientations to teaching	<ul style="list-style-type: none"> <li>• Teachers develop content specific orientations early in their careers which can reach back to their own experiences as a learner where content knowledge is limited</li> <li>• Experienced teachers may resist new content orientations, resorting to strategic compliance</li> </ul>

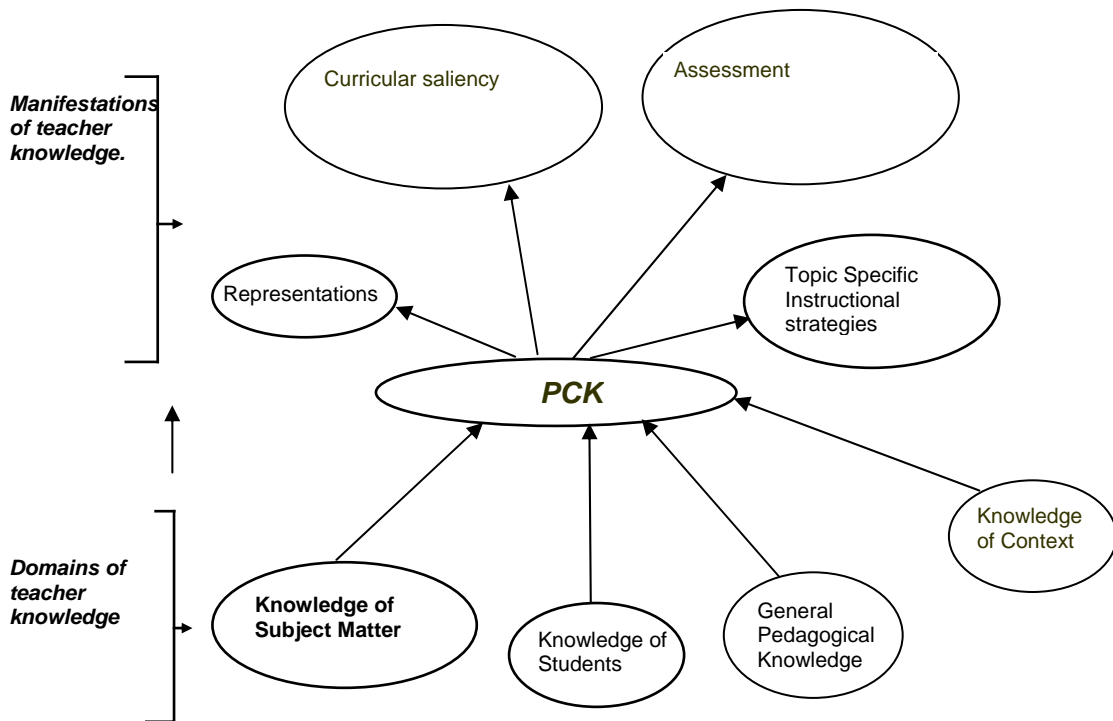
**Table 2. 1: Relevant findings on Teachers' SMK and beliefs (Gess-Newsome, 1999a)**

Gess-Newsome (1999b) distinguishes between integrative and transformative models of PCK. In the transformative model PCK is emphasised as an integrated product and in the integrative model there is a focus of the development of PCK with teaching experience.

Enfield (2000) argues that just as paradigms of scientific thinking have shifted, so have teaching paradigms. He highlights one of the problems as being the separation of the content and pedagogy in teacher education, as the content knowledge normally

comes from the disciplinary field and the pedagogy from the field of education. He further proposes a model in response to the need for PCK in which content and pedagogy are joined rather than integrated or intersected.

However Rollnick *et al's.* (2008) model of PCK emphasises the integration of these components of knowledge for the development of PCK. This model also shows the major role that subject matter knowledge, together with other factors, plays in the construction of teacher knowledge. The following Fig.2.1 shows their model:



**Fig 2.1: Rollnick *et al*'s. (2007) Tailored Model for PCK**

The lower part of the diagram shows four fundamental domains of teacher knowledge, viz., knowledge of subject matter, knowledge of students, general pedagogical knowledge and knowledge of context. PCK is considered to be the amalgam of these domains. A combination of these produces the observable products

in the classroom shown in the upper part which is referred to as manifestations. The manifestations include representations, subject specific instructional strategies, curricular saliency and assessment.

This model proved useful in this study to analyse the data in order to highlight the manifestations of PCK that were captured and portrayed during the interviews, lessons and reflections using the CoRe and PaP-eRs (Loughran *et al.*, 2004). Firstly, the model has guided the researcher in finding the evidence in the data which assists in identifying the constituents of PCK as highlighted in the bottom section of the model. Secondly it has assisted in identifying the manifestations which were visible in the classroom while the lecturers were teaching the topic, chemical equilibrium. Thirdly, it assisted in interpreting the evidence in the data which highlighted the lecturers' PCK. What is most fascinating about this model is the flexibility displayed when using it. In the case of the novice teacher, it can be used to highlight whether any one of the domains of teacher knowledge is lacking or any one of the teacher manifestations is not visible. Finally, the model makes the tacit more explicit. If the domains of teacher knowledge exist then automatically the manifestations of teacher knowledge will be visible. If the teacher manifestations are visible, then there will be evidence of the domains of teacher knowledge.

## **2.4 MODELS USED TO CAPTURE, DOCUMENT AND PORTRAY PCK**

In their case studies using vignettes of teaching practice (which included novice and experienced teachers) Geddis *et al.*, (1993) identified four categories of PCK, which are highlighted at the beginning of this chapter, that beginning chemistry teachers need to acquire to make it possible for them to move past a preoccupation with technical competence to a more critical stance involving the transformation of subject matter for teaching. This is supported by Shulman, (1986) who contends that an

important part of what skilled teachers do is transform subject matter content into forms that are accessible to their students. Geddis *et al.*, (1993) suggest that the articulation of this knowledge that teachers employ in the transformation provides an exciting focus on one aspect of what novice teachers need to learn how to teach.

Most of the literature on PCK highlights its tacit nature and the difficulty of recognising and documenting it. Geddis *et al.* (1993) used vignettes to highlight the well developed PCK of the experienced teacher as well as the need for the novice teacher to develop their PCK. Vignettes are narratives of teachers' classroom practice when teaching a lesson. The vignettes highlight the various components of PCK identified by Geddis and Wood (1997) in the description of the various accounts of teaching practice which include the teaching of difficult topics such as isotopes. In the account of teaching this particular topic, the vignette shows how an overall strategy was used to develop the concepts which frame the topic (topic specific strategy) and how the difficulties associated with the teaching of this topic were handled by the experienced teacher.

In another approach, Loughran *et al.* (2003) acknowledged the difficulty of recognising and documenting PCK and developed an analysis tool comprising two complementary elements given acronyms CoRes and PaP-eRs to capture and portray PCK. The CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional – experience Repertoires) were used to represent successful science teachers' PCK about a particular topic. The CoRes were developed by engaging small groups of experienced science teachers in activities that were designed to get them to articulate and share with others how they teach particular science topics. These discussions led to the identification of big ideas for teaching particular topics and led to the development of framing questions which formed the CoRe. The CoRe focused on the teachers' understanding of those aspects that represent and shape the content, and contribute to the content specific nature of PCK. While the CoRe summarises and

integrates aspects of content and practice that guide teaching, the PaP-eRs, which are narrative accounts of practice, bring to life the ideas in the CoRe.

Both CoRes and PaP-eRs were used to portray a composite practice. In this study a modified CoRe and Pa-PeRs were used as both methodological tools and as a model to capture and portray the PCK of individual teachers. The CoRe and PaP-eRs are referred to as modified, as they were used and composed differently to those of Loughran *et al.* (2003). They were not developed by engaging small groups of teachers in discussion about teaching chemical equilibrium, but they were developed in stages using data collected from individual interviews, observations of teachers teaching chemical equilibrium, reflections on the lesson taught and modified stimulated recall sessions (see chapter three). The discussion in chapter five shows that a modified CoRe and PaP-eRs can be used to capture and portray the PCK of any teachers (experienced and novice teachers alike).

## **2.5 DIFFICULTIES IN TEACHING AND LEARNING CHEMICAL EQUILIBRIUM**

According to Hackling and Garnett (1985) the science education literature of the 1980s contains numerous studies of student's understanding of scientific phenomena. There seems to be agreement that research in chemical education has shown that students at various levels have misconceptions about chemical equilibrium (Chiu, 2002; Bergquist and Heikkinen, 1990; Vilakazi, 1990; Hackling and Garnett, 1985; Wheeler and Kass, 1978). Chemical equilibrium is one of the more difficult concepts in general chemistry, owing to its abstract character (Voska and Heikkinen, 2000, p.160) and its "demanding the mastery of a large number of subordinate concepts" (Quilez-Pardo and Solaz-Poroles, 1995, p. 939). The results of a study by Hackling and Garnett (1985) reveal various misconceptions related to chemical equilibrium. Some of the misconceptions identified by authors above include the following:

- The rate of the forward reaction increases with time from mixing reactants until equilibrium is established (Hackling and Garnett, 1985);
- At equilibrium, if conditions are changed, the rate of the forward reaction can be increased while the rate of the other reaction decreases (Hackling and Garnett, 1985);
- There is no discrimination between reactions that go to completion and reversible reactions (Wheeler and Kass, 1978);
- Belief that the forward reaction goes to completion before the reverse reaction commences (Wheeler and Kass, 1978);
- Failure to distinguish between rate (how fast) and extent (how far) of reaction (Wheeler and Kass, 1978);
- Confusion regarding amount (moles) and concentration (molarity) (Bergquist and Heikkinen, 1990);
- Equilibrium is seen as oscillating like a pendulum and Le Châtelier's stress-then-shift logic reinforces this misconception (Bergquist and Heikkinen, 1990);
- The belief that a chemical reaction is compartmentalised into left and right half;
- The concentration of the reactants and products are equal at equilibrium (Gorodetsky and Gussenky, 1986);
- Equilibrium is not seen as a dynamic process but rather as static (Vilakazi, 1990);
- Equilibrium arrows are indicative of rates of forward and reverse reactions (Vilakazi, 1990); and
- Le Châtelier's principle: is it understood or applied correctly? (Vilakazi, 1990)

The concept, Le Châtelier's principle, in particular has been identified as problematic because of the way in which it is stated and its application. Voska and Heikkinen (2000) show that some students answer questions on the application of Le Chatelier's principle correctly, but using erroneous reasoning. Schmidt (1997) describes Le Chatelier's principle as 'not mere child's play' and shows how it is incorrectly formulated and applied even when the correct answer is obtained.

An important misconception held by students is the belief that the forward and reverse reactions happen in different containers independent, from each other. Misconceptions do not only exist amongst undergraduate chemistry students, but also amongst chemistry teachers (Quilez-Pardo and Solaz-Poroles, 1995). A comparative study by Banerjee (1991), using diagnostic tests rather than interviews, revealed that the extent of misconceptions is equally high among undergraduate chemistry students and secondary and senior secondary teachers.

## **2.6 GENERAL DIFFICULTIES RELATED TO LEARNING CHEMICAL EQUILIBRIUM**

Gorodetsky and Hoz (1985) argue that learning is influenced by students existing ideas. There are various theories which exist about how these misconceptions are acquired. According to Chiu (2002)'s theory of conceptual change, the concept of chemical equilibrium has constraint-based features (e.g., random, simultaneous, uniform activities) that might prevent students from deeply understanding the nature of the concept, chemical equilibrium. Furio *et al.* (2000) argue that many of the learning difficulties in the specific domain of chemistry such as chemical equilibrium are found not only in the ideas already possessed by students but in the strategic and procedural knowledge (functional fixedness and functional reduction) that is characteristic of everyday thinking. Banerjee (1991) asserts that there is a possibility that teachers might develop misconceptions in chemistry during their student days and that these are retained, despite professional experience over the years. These misconceptions could possibly be passed on to their students. Evrard *et al.* (1998) hypothesize that the structure of a teacher's oral discourse is a factor which influences student learning. They suggest that a pedagogically orientated discourse that suggests that there is a semantic equivalent between a scientific term and the word or phrase which has been used to paraphrase it can be a source of confusion and can mislead students.

Wheeler and Kass (1978) argue that in addition to certain prerequisite concepts and skills in chemistry, the treatment of chemical equilibrium calls for considerable abstraction and propositional thinking by the student. Buell and Bradley (1972) seem to support the latter idea as they suggest that for students to learn everything they are taught, they must have reached the logical operations state of development. Since not all students may be at this logical operations state, all we teach may not be learned, as logical thinking is needed in addition to procedural knowledge (Everard *et al.*, 1998)

Many views concerning the resistance to conceptual change in chemistry are held by science education specialists. Most researchers including Chiu (2002) and Furio *et al.* (2000) agree with Banerjee (1991), that according to constructivist theory of knowledge, it is very difficult to remove misconceptions from the minds of learners. Chiu (2002) argues that a considerable amount of research found that the process of knowledge construction involves the replacement or reorganization of conceptual frameworks. This implies that in order for students to replace their conceptions and reorganise their conceptual framework, the existing conceptions need to be untaught and then reconstructed. Hackling and Garnett, (1985) argue that learning science should be a restructuring of existing ideas rather than merely adding information to existing knowledge. According to Hewson and Thorley (1989), conceptual change has its epistemological requirements and must not be considered merely as change in content. It is therefore necessary to associate conceptual change with procedural and explicative knowledge (Kuhn, 1993; Wellington, 1989).

There are many reasons which underlie the difficulty of conceptual change especially in difficult topics such as chemical equilibrium. Those identified by Furio *et al.* (2000) include the following:

- The “common sense” reasoning that underlies the diverse areas of chemistry may suppose difficulties of a strategic type;
- Functional fixedness and functional reduction are not taken into account by teachers when they teach chemistry;



- Understanding conceptual change as deep restructuring not only in the ideas but ways of reasoning and it is not enough to take into account previous ideas;
- Historical and epistemological analyses of theory formation suggest that a paradigm change is not easy, nor can it be reduced to changes that happen exclusively in concepts;
- In general, these conceptual changes are associated with other changes, such as new ways to view phenomena (ontological changes); and changes in interests, attitudes, or assumed values by the community (axiological changes);

According to Gorodetsky and Hoz (1985), curriculum developers and science teachers attempt to create cognitive structures in learner's minds which are similar to theirs by attempting to transfer these structures to the students via curricula, programs and courses, in most cases in an implicit manner. It seems that research is very important when dealing with misconceptions as it provides the necessary tools which could possibly identify misconceptions which exist amongst both students and teachers. Gorodetsky and Gussarky (1986) found that evaluative tests can provide teachers with useful information about students' learning difficulties and those evaluative methods (not test or examinations) could possibly be used to identify misconceptions and these are provided by research methodologies.

## **2.7 CONTENT-SPECIFIC PCK WITH RESPECT TO CONCEPTS IN CHEMICAL EQUILIBRIUM**

Research does not only provide us with the necessary tools to identify misconceptions but also provides ways and strategies of dealing with certain difficult and problematic concepts in learners. Misconceptions in chemical equilibrium can be addressed using effective, topic-specific teaching strategies (Vilakazi, 1990; Quilez-Pardo and Solaz-Poroles, 1995). These topic-specific teaching strategies are embedded within the concept of pedagogical content knowledge. Peterson and Treagust (1995) argue that

in addition to the knowledge base for teaching, teachers need to be able to make important decisions regarding their teaching. Pre-service teachers need to have developed their pedagogical reasoning skills and have improved their knowledge of the subject matter by the time they graduate. Van Driel *et al.* (1998) on the other hand identified teaching experience as being the major source of PCK and adequate subject matter knowledge as a prerequisite. According to Geddis *et al.* (1993) it is important to make explicit the tacit pedagogical content knowledge of experienced teachers. Once tacit knowledge is made explicit, cooperating teachers not only have greater control over their own use of it but are also in a position to pass it on to novice teachers. A teacher's PCK, which is evident during teaching practice, could be influenced by his/her own understanding and conception of a concept. The findings of Tulberg *et al.* (1994) show that an educator's conception of 'the mole' was found to be a decisive factor when choosing the teaching approach and that the students' conceptions mirror the educator's conceptions described by the fundamentals.

Gorodetsky and Gussarky (1986) believe that revealing difficulties in problem-solving is part of the teacher's evaluative tasks, and is a prerequisite step to a change and improvement in teaching. According to Hackling and Garnett (1985), information regarding the preconceptions students bring to instruction and the misconceptions held following instruction is essential for the improvement in science teaching. The pedagogical task is to teach in such a way that students participate in the constructive process, because doing so improves meaningfulness and retention of declarative knowledge and increases consciousness and generalisability of the procedural knowledge (Lawson, 1994). Geddis *et al.* (1993) argue that the tension between focussing on the learner and focussing on subject matter is one part of what makes teaching such a complex endeavour. The work done by Van Driel *et al.* (1998), with chemistry teachers, resulted in the identification of elements of PCK. Teachers could use these to promote understanding and conceptual change by discussing the anomalous results of certain chemical experiments with students. In addition they could challenge student's conceptions by urging them to explain phenomena which

indicate the reversibility and the incomplete conversion of chemical reactions. These concepts could form some of those that will be focused on in this study. De Berg (2004) used a pedagogical history approach to promote students' understanding of the nature of chemistry which was informative about the way chemical knowledge is developed. The prompts in his study, like the prompts in the CoRe of this study acted as scaffolding to support the learners' progress in knowledge acquisition. Furio *et al.* (2000) suggests that students' ability to analyse consistency of results using different problem-solving strategies can be developed by avoiding functional fixedness.

Schmidt (1997) presents an argument about the formulation and application of Le Chatelier's Principle and concludes that incorrect formulations of Le Chatelier's Principle should not be taught. He would rather accept short versions of Le Chatelier's Principle and therefore his suggestion for teaching is to try and utilize as much as possible with the following two models:

- The model of dynamic equilibrium; and
- The law of mass action, what he considers to be a mathematical model.

According to Buell and Bradley (1972), equilibrium should be a dynamic concept to the science student. They assert that the equilibrium between the undissolved solute and the dissolved solute which was used by Mr Moerane, the experienced teacher, in this study, is an extremely good example of dynamic equilibrium. This example which could be used to help students understand dynamic equilibrium is less complex, more concrete, and closer to everyday ways of thinking (Geddis *et al.* 1993). According to Banerjee (1991) although the rate approach (the rate of the forward reaction equals the rate of the reverse reaction) to teaching chemical equilibrium has been advocated, the rate approach should be used with caution and should not be overemphasized in order to avoid the possible development of misconceptions. He further states that it is also only theoretically sound for elementary reactions and thus only truly applicable for a limited number of reactions.

Research studies have recommended the following for teaching:

- A greater emphasis on the quantitative aspects of equilibrium;
- A greater differentiation in the range of examples presented to students when discussing Le Chatelier's Principle; and
- A greater emphasis on a laboratory approach.

Despite these studies recommendations, Treagust and Gräber (2001) argue that there are very few detailed descriptions in the literature about how these recommendations for teaching the topic chemical equilibrium have been implemented and the effects that the implementation has on student learning.

According to Geddis *et al.* (1993) consideration of curricular saliency can play a pivotal role in assisting teachers to deal with the tension between 'covering the curriculum' and 'teaching for understanding'. Like the Western Australian upper secondary syllabus as outlined by Hackling and Garnett (1985), the South African Technikon syllabus emphasised a qualitative treatment of chemical equilibrium with very little work on calculations involving equilibrium constants. It included the characteristics of chemical equilibrium (macroscopic constancy, dynamic nature); the meaning of  $K_c$ , Le Châtelier's principle; and the application of this knowledge to a qualitative understanding of topics such as acid strength, solubility and some industrial processes. Very few reactions are encountered by students which illustrate the reversible nature of chemical reactions. Hackling and Garnett (1985) also suggest a teaching sequence which is similar to the teaching sequence found in the CoRe developed in this study, although the CoRe suggests the why of the teaching sequence.

In their discussion of oral discourse in the classroom, Evrard *et al.* (1998) suggest that it is important to consider the oral contributions of the pupils as these may change the conceptual structure of the lesson as envisaged by the teacher at the preparation state. Consideration of the oral contributions is an important part of the classroom and students' context and of PCK as outlined in Rollnick *et al.*'s. (2007) tailor made

model of PCK which will be discussed under models of PCK. The oral discourse needs to be considered during preparation and teaching of the lesson. Oral discourse analysis could also be useful for trainee teachers.

The results of a study by Niaz (1995) supports the hypothesis that students who perform better with problems requiring conceptual understanding also perform significantly better with problems requiring manipulation of data, i.e. computational problems. The findings of this study can be summarised as follows:

- Those students who have a conceptual understanding of the underlying principles (rate of the forward reaction decreases as the reaction gets going), subsequently perform extremely well on other related aspects of chemical equilibrium. This suggests that by emphasising certain key aspects of a topic we may start a chain reaction that may help facilitate conceptual understanding;
- Another important finding of this study is that given an opportunity, and after having been exposed to closely related alternative probing questions, students give up a certain mode of thinking, at least partially. Furthermore, students adopt an alternative view that apparently contradicts their previous thinking;
- Finally, this study has identified student difficulties in various aspects of chemical equilibrium.

## **2.8 CONCLUSION**

The literature which has been reviewed, and the theoretical framework discussed above, has provided the basis for the next chapter, which discusses the research method and design of this study.

## **CHAPTER 3: METHODOLOGY AND RESEARCH DESIGN**

### **3.1 INTRODUCTION**

In this chapter the following will be discussed:

- The methodology;
- The research design of the study;
- The sample used;
- The various data collection tools; and
- The ethics, values, validity and reliability that were considered will also be discussed.

### **3.2 RESEARCH DESIGN**

There are certain characteristics that distinguish qualitative from quantitative research. Some of these characteristics include the aim of the research (what the researcher would like to find out in the enquiry), the purpose of the enquiry, the type of data required to answer the research questions and the data collection techniques (Opie, 2004). A qualitative research design involves emphasised objectivity and quantification of phenomena (Schumacher and MacMillan, 2006) and it can be experimental and non-experimental. The research data are normally made of numbers, statistics, and involve structure and control. Alternatively qualitative research alternatively is described by Fraenkel and Wallen (1996) as:

*“Research studies that investigate the quality of relationships, activities, situation, or materials are frequently referred to as qualitative research”* (1996: p 442).

Qualitative research designs normally emphasise the collection of data in a natural setting using data collection techniques which would enable the researcher to obtain a

detailed description (narrative description) of what goes on in a particular situation or activity. Most of these data are in the form of words (Schumacher and Macmillan, 2006). Since the aim of this study was to find out about the lecturers' PCK with respect to the topic chemical equilibrium, a detailed description of the lecturers' practice while teaching this topic had to be obtained. A qualitative research design was therefore chosen for this study.

These data were collected in the form of field notes through observations and interviews. A case study was appropriate in this investigation as it involved a detailed study of the practice of the two lecturers (Cohen and Manion, 1980), in the access chemistry programme within the Access Programme at the Technikon Witwatersrand. A case study also provides for a more detailed and exploratory research approach (Dyer, 1995) which is needed to answer the research questions, which are documented in chapter one of this study. The power of a case study approach is that it allows features of behaviour or experience, which are shared by many people, to be studied in detail and depth (Dyer, 1995), in this case the behaviour and experiences of the two chemistry lecturers while teaching chemical equilibrium. The results from a case study cannot be generalised as the data collected is not from a sample that is in some way representative of a population to which generalisation is sought (Guba and Lincoln, 1983). However, this method of research provided for a thick description of data which was needed when documenting the data collected during the interviews and the observation of the two lecturers.

### **3.3 SAMPLE**

Purposeful sampling to maximize the range of information to be collected (Guba and Lincoln, 1983) was used to select the subjects for this study. As the study was carried out at the Technikon Witwatersrand (now The University of Johannesburg, Doornfontein campus), where the researcher is presently employed as an access chemistry facilitator (senior subject coordinator), two chemistry lecturers, who

lectured Access Chemistry to the bridging students, participated in this study. Lecturer 1, pseudonym Mr Dhlamini, is an expert in the field of chemistry. During the study he was studying for a PhD in Catalysis at a neighbouring university. At the time of data collection, he had only eight months experience teaching in the Access Chemistry programme and approximately five years tutoring experience in a similar programme at another higher education institution. He lectured two access chemistry classes of thirty students and one class of ten students. Mr Dhlamini's practice was observed and documented by the researcher while he taught both engineering groups. Lecturer 2, pseudonym Mr Moerane, has a teaching qualification and has taught chemistry at senior secondary level. He has nine years senior secondary school teaching experience. However, when the data was collected, he had been teaching chemistry in the Access Chemistry programme for eight months. He lectured four access chemistry classes of 30 students, two groups comprising of health sciences (known as pre-Bio) students and the other two groups, engineering students. Mr Moerane's practice was observed and documented while he taught the one engineering and the one health sciences class.

### **3.4 INSTRUMENTATION AND DATA COLLECTION**

#### **3.4.1 Data collection**

For the purposes of triangulation, data were collected using interviews and by writing field notes during observations. Cohen and Manion (1980), suggest triangulation techniques when a more holistic view of educational outcomes is sought. In this study a holistic view of the lecturers' practice of pedagogical content knowledge was sought. The interviews were audio taped and the observations were video taped. The data were collected by the researcher who conducted the interviews and did the observations. Teachers' written preparation and transparencies used during the lessons were also collected.

#### **3.4.2 Observations**

At the heart of every case study lies a method of observation (Cohen and Manion,



1980). Observations were important in this study to gain an accurate indication of the lecturers' activities (Fraenkel and Wallen, 1990). The researcher was also able to observe other points of interest as they occurred, especially the interaction between the lecturer and the students. The researcher observed two groups per lecturer. To minimize the influence of the researcher's presence on the lecturers' practice, and students' reactions, the researcher observed more than one lesson in Mr Moerane's classroom before the formal observation began. From the seemingly relaxed atmosphere during the observations it became clear that Mr Moerane and the students were comfortable with an observer present. An observation schedule could have been prepared beforehand, but I preferred recording field notes during the lesson. In this way the researcher was able to make fuller observations than someone relying on recollection. If only field notes are recorded, it is very difficult to revert and check observations afterwards. The lessons were therefore videotaped as well. It was also easier for the researcher to take in-depth notes as she was not a participant observer (Fraenkel and Wallen, 1990). The researcher observed two of Mr Dhlamini's classes. One of the classes had ten engineering students and the other was made up of twenty four Pre-Bio students (students who have entered the access programme in preparation to study courses offered by the Faculty of Health Sciences) who required basic Chemistry with a focus on organic chemistry. The researcher did not have an opportunity to do observations before data collection occurred in these classes. However, the engineering students were familiar with the researcher as she lectured Access Physics to their class. They also seemed very relaxed during the observations.

If the researcher missed any valuable information during most of the observations, it was picked up on the videotape. The videotape not only gave the verbal information, but also the body language of the lecturer being observed. The four lessons were observed over a period of two weeks. As a non-participant observer the researcher obtained a more holistic picture and seemed least likely to affect the actions (Fraenkel and Wallen, 1990) of the lecturers. The field notes were then typed a few days after the lessons were observed. After the field notes had been written, the researcher

reviewed the notes with the relevant lecturer to confirm that it was a true reflection of the events.

### **3.4.3 Interviews**

The researcher carried out one interview per lecturer before the lesson on chemical equilibrium and one interview per lecturer after the lesson had been taught. The researcher used an interview schedule during the pre-lesson interview (see Appendix A for interview schedule). The interview schedule was developed by the researcher. The questions that were asked from the interview schedule were developed from the research questions to try to maintain the focus of the interview but also to allow the interviewee to speak freely. When developing the interview schedule, the researcher also took possible probing into account. Therefore, some of the probing questions were included in the interview schedule. The interview schedule was piloted by the researcher a week before Mr Moerane's pre-lesson interview. The purpose of interviewing the lecturer in the researcher's office 20 minutes before each lecturer began lecturing the topic chemical equilibrium was to find out what was on his mind (Fraenkel and Wallen, 1990) when preparing for the lesson on chemical equilibrium. A number of key issues were raised from the questions on the interview schedule in conversational style (Cohen and Manion, 1980). The interview method complemented the observations as it was highly flexible, allowing the researcher to both probe the areas of the knowledge domain of particular interest and to let the subject speak freely, while constantly checking his or her spontaneous remarks for those that proved genuinely revealing (Posner and Gertzog, 1982). During the post-lesson interviews, the responses were not in line with the researcher's expectations. She therefore asked the lecturers to record their reflections about the lessons they had taught. To avoid the danger of the possible misinterpretation of responses, and for validation purposes (Posner and Gertzog, 1982), the interviewer confirmed the interpretation with the interviewees, by asking them to read and confirm the interview transcripts (see Appendix B for sample transcript). After the interview transcripts were perused, the researcher realized that she had missed possible opportunities for

probing and therefore went back to the lecturers to acquire the information by using modified stimulated recall. The interview after the lesson was important for the researcher to check the accuracy of – to verify or refute – the impressions he or she has gained through observation (Fraenkel and Wallen, 1990). The interviews were audiotaped as mechanically recorded data (Schumacher and McMillan, 1993) increases the reliability of the data. They were transcribed over a period of one month by the researcher.

Being a novice interviewer, the researcher agrees with Adams and Schvaneveldt (1991) that the interview is not a very simple method of data collection. It requires a certain amount of skill. The interview was particularly useful in this study for the following reasons:

- The researcher could constantly go back to the interviewees to confirm interpretations and to validate data;
- As the interviewer, the researcher could explain the purpose of the study, discuss the interview and respond to any questions that the respondents asked;
- It improved the quality of data specific to the interview;
- Only two lecturers were interviewed;
- The two lecturers and the researcher were employed at the Technikon Witwatersrand; it was therefore convenient for all parties to meet and did not involve any cost.

However, there was a distinct possibility of bias (Adams and Schvaneveldt, 1991) as the interviewer is the facilitator (the two person report to her as their supervisor) of the Access Chemistry programme and the interview was (conducted) in her office. There was also a possibility that the interviewees could have been intimidated by being interviewed in the facilitator's office. In order to reduce the possibility of bias and to make the interviewees feel at ease, the researcher did the following:

- Explained to the interviewee that the purpose of the interview was to find out about his ideas related to information required for the research project;

- Stated that throughout the duration of the interview the interviewee should not view the researcher as the chemistry facilitator but rather as the researcher who was seeking his professional opinion;
- Explained that there was no other private space available for the interview except for the researcher's office;
- Moved out of the seat where she normally sits during consultation with the lecturers. The researcher moved her seat so that she could sit in a very relaxed position to make it seem as if they were merely having a conversation;
- Explained that if at any time during the interview the interviewee felt uncomfortable, he should feel free to withdraw.

It was also the first time that the interviewer had conducted an interview. It was therefore highly possible that the interviewer did not utilise all the chances that were available to probe further. However, the researcher did pilot the interview beforehand.

### **3.4.4 Reflections**

As a result of the researcher not eliciting the required information from the interviewees in the interview after the lesson, the researcher requested each of lecturers to write reflections on the lesson that they had taught (see Appendices L and M). Since the reflections that were written by both lecturers were very short, the researcher decided to set up an interview with the two lecturers and asked each to respond to the prompts that had been taken from the CoRe (which has been highlighted in Appendices C and D) of Loughran *et al.* (2003 and 2004). This reflection session, using the prompts, proved most useful especially during the documenting and portraying of the PCK (the development of a CoRe and PaP-eRs). The use of the representation of CoRe and PaP-eRs as methodological tools to develop a modified CoRe and PaP-eRs for Mr Moerane and Mr Dhlamini is discussed in great depth in chapter four. The data from the interview transcripts, the

field notes, the written reflections and the CoRe prompts were used to develop a CoRe and two PaP-eRs.

### **3.4.5 Stimulated Recall**

During the interview after the lesson was taught, the researcher asked the lecturers to reflect on the lesson they had taught and to give feedback based on their reflections. The lecturers found it difficult to reflect and to articulate the required information. The researcher then requested each lecturer to write his reflections on the lesson. As mentioned in the previous section, the lecturers' written reflections after the lessons were very short. The researcher decided that the lecturers should have a stimulated recall session which could provide an opportunity for the lecturers' to re-live the original teaching situation. They could then reflect accurately on the lessons during the interview - using the prompts from the CoRe – and thereby serve as a validation of the data which was included in the interview transcripts, the CoRe and the PaP-eRs.

Most research on or involving stimulated recall has been carried out in the education and medical field. Barrows (2000) encourages the use of stimulated recall and reports on stimulated recall being used widely by researchers to probe into physician clinical reasoning. He reported on Bloom's idea: that the basic reasoning behind stimulated recall is that:

*'...a subject may be enabled to relive an original situation with great vividness and accuracy if he is presented with a large number of cues or stimuli which occurred during the original situation.'* (Barrows, 2000: p 1)

According to Nuthall (1999), the use of audio- and video-recordings to stimulate recall of cognitive processes in the classroom has been reported in a number of studies. Most of the studies report on Bloom (1953) using sound recordings as a stimulus although various stimuli such as written records, audiotapes and videotapes have been used in educational research. Stough (2004) used videotaping, enriched by field notes, for stimulated recall in classroom observation and professional

development of teachers. She asserts that stimulated recall can promote reflective teaching practice which this study has identified as being an important aspect in the development of PCK.

In this research study the stimulated recall was modified. The video recordings were used to validate the written records in the form of PaP-eRs and CoRes and the interview transcripts were used as stimuli for stimulated recall sessions. The video recordings were not used as the stimulus for the stimulated recall. Immediately after the lesson, the researcher met with each of the lecturers to validate the data that had been collected during the interviews in the form of written notes. Once the data had been validated, it was typed and the audiotape transcribed. The typed data was updated using the transcribed data and once again validated by the relevant lecturer. After I had recorded the field notes during each observation, I met with the relevant lecturer to clarify certain issues pertaining to the lesson taught. The field notes were typed, and together with the interview and the written reflections after the lesson, the PaP-eRs were developed. Each of the lecturers was given an opportunity to recall what happened during the interview and the lesson from the relevant PaP-eR. Where necessary, the video recording was used to check the data in the PaP-eR. The PaP-eRs were developed first from the interviews and the field notes. It is only after the PaP-eRs had been developed and the lecturers had reflected on the lessons taught using the written stimuli, that the researcher used the CoRe as an interview tool during the reflective interview. The CoRe was developed only after the stimulated recall and reflective interview data had been collected.

### **3.5 ETHICS**

At the time that the proposal was developed, the formalised ethics application process had not been properly instituted. Nevertheless, the researcher did her best to ensure that ethical principles were adhered to. Ethics was one of the most important considerations in this research study. As soon as the researcher had decided on her

research topic, she approached the Head of the Academic Support Unit to discuss the possibility of conducting my Masters of Science in Science Education Research Project in the Access Programme. Permission was granted on behalf of the Technikon Witwatersrand and the Academic Support Unit. Once this decision had been communicated to me by the Head of Department, I approached Mr Moerane and Mr Dhlamini to find out whether they were prepared to participate in the study, and explained the nature of the study to them. I also explained that if they felt uncomfortable at any stage they could withdraw. Both participants agreed that they would participate. Finally, I spoke to the Access Chemistry students, to explain the purpose of the study and the role that they would play. I also explained that they were not compelled to participate. Consent forms were signed by the Head of the Access programme, the students and the lecturers (see Appendix G for Consent forms).

### **3.6 VALIDITY AND RELIABILITY**

Validity and reliability apply to observations researchers have made and to the response they receive from the interview questions asked (Fraenkel and Wallen, 1990). Guba and Lincoln (1983) prefer to use the four terms: *credibility, transferability, dependability and confirmability*, in place of internal validity, external validity, reliability and objectivity, respectively. In this study, as in all qualitative research, the terms validity and reliability will be used and are very important. Fraenkel and Wallen emphasise this importance and define validity as

*“...the appropriateness, meaningfulness, and usefulness of inferences researchers make based on the data they collect”* (1990: p 461).

To enhance the validity of this research study the following strategies were used:

- The triangulation of data by using interviews and observations to collect data;
- The interviews were audio taped and the lessons were video taped;

- Both Mr Moerane and Mr Dhlamini were interviewed more than once (Fraenkel and Wallen, 1990);
- Throughout the research process, data was validated by both researcher and the participants being observed;
- The data included in the CoRe and PaP-eRs was reviewed by both researcher and the relevant lecturer;
- After the CoRe and PaP-eRs were developed they were reviewed by the researcher and the lecturer.

Fraenkel and Wallen describe reliability as

*'...the consistency of these inferences over time'* (1990: p 461).

The reliability was enhanced by interviewing each lecturer more than once to make sure that there was consistency in their individual reports and by doing observations over a period of time. Consistency of the setting or situation being observed or heard by the researcher over a period of time indicates strongly that there was consistency (Fraenkel and Wallen, 1990).

### **3.7 CONCLUSION**

The above discussion highlights the importance of an appropriate and well developed research design in order to achieve the purpose of the research study. The next chapter discusses the development of the PaP-eRs.



## **CHAPTER 4: THE DEVELOPMENT AND REPRESENTATION OF THE CoRe AND PaP-eRs**

### **4.1 INTRODUCTION**

As mentioned previously, Loughran *et al.* (2003) developed and used two different but complementary tools known as CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional – experience Repertoires) to represent successful science teachers' PCK about a particular topic. Although these formats were used to portray the PCK of successful science teachers, the researcher believes that they can be used to capture and portray the PCK of any teacher. The tools of CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional – experience Repertoires) have therefore been used in this research project to capture and portray the PCK of two lecturers, Mr Moerane and Mr Dhlamini.

This chapter will focus on the PaP-eRs and CoRe (Loughran *et al.*, 2004) as a model. The following will be included in the discussion:

- An explanation of what a PaP-eR is, as outlined by Loughran *et al.* (2003 and 2004);
- The development and representation of Mr Moerane's and Mr Dhlamini's PaP-eRs (see Annexure C and D respectively) referred to as a resource folio by Loughran *et al.* (2006);
- An explanation of what a CoRe is, as outlined by Loughran *et al.* (2003 and 2004);
- The use of the CoRe as a tool to represent Mr Moerane and Mr Dhlamini's CoRe;
- A comparison of the development Mr Moerane and Mr Dhlamini's CoRe with Loughran *et al.*'s (2003 and 2004) CoRe;

- A representation of Mr Moerane and Mr Dhlamini's CoRe; and
- A discussion of important aspects of the content in Mr Moerane and Mr Dhlamini's CoRe.

## 4.2 WHAT ARE PaP-eRs?

Loughran *et al.* (2003) describe PaP-eRs as follows:

- PaP-eRs are narrative accounts of teacher's PCK for a particular piece of science content. They are about teaching particular content in a particular context;
- Well-constructed PaP-eRs bring the CoRe to life and shed new light on the complex nature of PCK;
- PaP-eRs attached to different areas of the content are designed to highlight some of the different blends of elements that jointly contribute to an individual's or group of science teachers' PCK.

In this study, Mr Moerane and Mr Dhlamini's PaP-eRs can be described as narrative accounts of the respective lecturers PCK for chemical equilibrium. They are windows into the lessons (Loughran *et al.*, 2003) taught by the respective lecturers in a certain context and bring the CoRes to life (see Appendices A and B for Mr Moerane's and Mr Dhlamini's CoRes). Although these PaP-eRs were not written according to those by Loughran *et al.* (2003; 2004), they served as a valuable resource in this study for the development of the CoRe which is outlined in section 4.6 and as an important data analysis tool.

### **4.3 The Development and construction of Mr Moerane and Mr Dhlamini's PaP-eR**

Although Mr Moerane's and Mr Dhlamini's PaP-eRs( see Appendices E and F ) have been modelled on the PaP-eRs developed and constructed by Loughran *et al.* (2003) the following differences are evident:

- Mr Moerane's and Mr Dhlamini's PaP-eRs are individual PaP-eRs developed from each individual's PCK whereas Loughran *et al.* (2003) PaP-eRs were developed from PCK of groups of science teachers.
- Mr Moerane's and Mr Dhlamini's PaP-eRs have been documented differently in order to suit the context of the lecturers who teach in the Access Programme in the Academic Development Division at the University of Johannesburg.

In order to develop and construct Mr Moerane's and Mr Dhlamini's PaP-eRs (see Appendices E and F respectively) the researcher used interviews with each individual lecturer, observations of his lectures, the lecturer's self-reflection and stimulated recall together with researcher's commentary. Each data source forms the subheading of the PaP-eR of each lecturer and a discussion of the data is included in the PaP-eR. Loughran *et al.* (2003) highlights the use of a variety of formats (e.g. an interview, observer's voice, journals, window into a lesson, student's voice and actions, an annotated teaching resource, and so on) so that the portrayal allows the reader to identify with the situation and, as a result of the particular framing of the pedagogy, content and context, to draw meaning from it. In the construction of the PaP-eRs in this study the researcher has attempted to use an interview, observer's voice and a window into a lesson to create meaning. Although the PaP-eR is linked to the CoRe, some of the information which has been included in the CoRe that the lecturers did not articulate during the interview was taken from the PaP-eRs once they had been constructed. The researcher would also like to highlight the fact that the PaP-eRs in

this study are based on non-idealised teaching where teachers have not been exposed to PCK and reflective practice.

Each PaP-eR was developed from the lecturer's interview transcript, the field notes taken during observation of the lessons and the written reflections of the lecturer. The subheadings of the PaP-eR were written based on the various data sources. The researcher then analysed the interview transcript and based on the interview questions asked, certain themes viz. planning, approach to teaching, prior knowledge, content knowledge, resources and assessment activities emerged, and these formed the headings under the interview subheading. The researcher then wrote a narrative account of the interview based these headings. The observation of the lesson was also analysed in the same way as the interviews. When the researcher analysed the data from the lesson, it became evident that there are various concepts such as equilibrium, closed systems, reversible reactions, the equilibrium constant expression and dynamic equilibrium which frame the topic chemical equilibrium. There are also conditions for chemical equilibrium, Le Chatelier's Principle and assessment of the concepts which are very important. Themes also emerged from the concepts together with the analogies used to teach the concepts. These themes were then used to develop the headings under the subheadings. The researcher then wrote a narrative account of the lecturers' practice according to the various themes. The teaching strategies of Mr Moerane and Mr Dhlamini which are discussed and illustrated in chapter 6 became evident. On reflection and thinking about the information in the PaP-eRs, the two "Big Ideas" which are explained and discussed in section 4.11 in this chapter emerged. In order too make it flow, the PaP-eRs included the researcher's commentary. The teachers' reflections were too short and lacked substantial information for the researcher to analyse.

#### **4.4 WHAT IS A CoRe?**

Loughran *et al.* (2006) describe a CoRe in the following way:

*'A CoRe (Content Representation) provides an overview of how teachers approach the teaching of the whole topic and the reasons for that approach - what content is taught and how and why - in the form of propositions. Importantly, a CoRe refers to the teaching of a particular topic to a particular group of students' (2005: p 21).*

Although the CoRe represented in this chapter is modelled on the CoRe of Loughran *et al.* (2003), it does not represent the PCK of successful science teachers but of teachers whose practice is non-idealised and whose PCK is still being developed. This CoRe (included in Appendices C and D), will be structured in exactly the same way as that of Loughran *et al.* (2003) but has been modified with respect to its development and the way it was used. It was modified to suit the context of the lecturers in this research study and it refers to the teaching of chemical equilibrium to access students (these are students who lack the prerequisite skills and knowledge to enter first year university even though they do show potential).

## **4.5 THE STRUCTURE OF THE CoRe**

The CoRe consists of a grid with 'big ideas' (Loughran *et al.* (2003, 2004) considered heading the columns while the rows consist of the prompts which are answered for each big idea. The prompts/ framing questions are:

1. What do you intend the students to learn about this idea?
2. Why is it important for students to know this?
3. What else do you know about this idea (that you don't intend students to know yet)?
4. Difficulties/limitations connected with teaching this idea.
5. Knowledge about student thinking that influences your teaching of this idea.
6. Other factors that influence your teaching of this idea.
7. Teaching procedures.

## 4.6 THE DEVELOPMENT OF THE CoRe

The CoRe developed by Loughran *et al.* (2003), is a generalisation of a group of teachers' responses in which they listed what they considered to be the 'big ideas' for teaching the topic 'chemical reactions' to grade 10. This also included the information they provided in response to the different aspects of knowledge and practice according to the various prompts. According to Loughran *et al.* (2004), the CoRe was developed from small group discussions with expert science teachers who had a well-developed PCK in the following way:

*"...The framing questions/prompts in the left hand column of the CoRe were developed from the teachers' response to a task where they had to consider what the main ideas or concepts were to teach a particular content area and how they would go about helping students to understand those ideas"(2004:p).*

The CoRes in this chapter were developed in three stages which are described as the pre CoRe, elaborated CoRe and the reflective CoRe. Unlike Loughran *et al.* (2003, 2004) where the CoRe which was developed from interviews only, this CoRe (see Appendices C and D) was developed from all the data sources. The development of this CoRe will be discussed below.

## 4.7 THE DEVELOPMENT OF MR MOERANE AND MR DHLAMINI'S CoRe

Once the data had been collected, the model of CoRe seemed most suitable to represent the PCK of the lecturers in this research study. The CoRe represented in this chapter was developed from the data collected from individual interviews with lecturers and their responses to the interview questions listed in the interview schedule (shown in Appendix A). This occurred before teaching the chemical equilibrium lesson, their teaching practice on chemical equilibrium, written

reflections after the lesson, and information obtained from stimulated recall, using the CoRe as an interview tool and the prompts to elicit information on the lecturers' knowledge and practice. Since the articulation of PCK increased in richness with each successive data collection, it was decided to build the CoRe in three stages, referred to as the pre-CoRe, elaborated CoRe and reflective CoRe. The stages and their data sources are shown in table 4.1 below.

STAGE	DATA SOURCES
Pre-CoRe	Pre-interview
Elaborated CoRe	Observations
Reflective CoRe	Post-interview, written reflections and stimulated recall interview

**Table 4.1. The three stages, the pre CoRe, elaborated CoRe and reflective Core, of development of the CoRe and the data sources for each stage.**

The CoRe has therefore been used as a tool in this particular context to attempt to capture and represent the lecturers' PCK in chemical equilibrium from all those data sources. Since Mr Moerane can be regarded as an experienced teacher, and Mr Dhlamini as an inexperienced teacher, two separate CoRes were developed. The full CoRe for each lecturer showing all three stages is shown in Appendices C and D. Below is an illustration of how the information was put together showing the 5<sup>th</sup> prompt for Mr Moerane, as an example.

#### **4.8. Pre-CoRe**

The pre-CoRe which is represented in the second column of tables in Appendices C and D was developed from the interview before the lesson was taught. The interview was not based on the CoRe prompts but on the interview schedule (included in Appendix E). The responses to the prompts were therefore obtained indirectly from

the responses to the interview schedule. It can be described as a very limited CoRe since it does not adequately reflect the CoRe described by Loughran *et al.* (2003). The response to the question “what do you intend the students to learn about this idea?” is given in the form of concepts, rather than what was intended for the student to learn about that concept. This information was taken from each lecturer’s response to how he would go about teaching the topic, chemical equilibrium to the students. At this stage Mr Moerane listed two concepts. This shows that Mr Moerane was aware of the framework of concepts which are included in teaching the chemical equilibrium. The following represents a section of Mr Moerane’s pre-CoRe:

PROMPT	Pre CoRe
<b>5. Knowledge about students’ thinking which influences your teaching of this idea.</b>	<ul style="list-style-type: none"> <li>• He considered how he viewed the students’ understanding of equilibrium.</li> <li>• It was important for the students to understand the concept of ‘chemical equilibrium before moving on to other concepts.</li> </ul>

**Table 4.2 A section of Mr Moerane’s pre- CoRe.**

## 4.9 ELABORATED CoRe

The elaborated CoRe which is represented in the third column of the tables in Appendices C and D was developed from the PaP-eRs which are based on observation of teaching. The responses to the prompts were also obtained indirectly from what the lecturer did in class and therefore sometimes involved the researcher’s interpretation. The information included in response to prompt 1 “what you intend the students to learn about this idea” was taken from what the lecturers said during the



lesson about the particular concept rather than just a listing of the concept. This information was not articulated during the interview. This also makes explicit the tacit nature of the teacher's knowledge that is used for teaching.

As the full version of the CoRe in appendices C and D show, the elaborated CoRe was most valuable in prompts like "knowledge about students' thinking which influences your teaching of this idea" where the lecturer's thinking was more fully explicated. The response to "knowledge about students' thinking which influences your teaching of this idea" involved the researcher's interpretation because Mr Moerane used the concept of phase equilibrium very effectively to explain the 'dynamic nature' of equilibrium and also mentioned the use of it in his overall strategy that he described during the interview. Mr Dhlamini used gases and endothermic and exothermic reactions which is background knowledge that students would have encountered previously at school. The response to teaching procedures (and particular reasons for using these to engage with this idea) also involves the researcher's interpretation because the teaching procedures of both lecturers were observed by the researcher during the lesson. Looking at data on responses to the following prompts shows that it was very difficult to respond by merely observing a lesson because this information can only be communicated to the researcher by the lecturers:

- Why it is important for students to know this?
- What else you know about this idea (that you do not intend student to know yet)?
- What difficulties/limitations are connected with teaching this idea?
- Which other factors influence your teaching of this idea?

In the example used of prompt 5 "knowledge about students' thinking which influences your teaching of this idea" one further idea was added as shown below in table 4.3. The following represents a section of Mr Moerane's elaborated CoRe:

PROMPT	ELABORATED CoRe
<b>5.Knowledge about students’ thinking which influences your teaching of this idea.</b>	<ul style="list-style-type: none"> <li>The students’ encountered phase equilibrium in module 1 of the chemistry material used by the access students.</li> </ul>

**Table 4.3 A section of Mr Moerane’s elaborated CoRe.**

#### **4.10 REFLECTIVE CoRe**

The Reflective CoRe was developed from the interview after the lesson, written reflections and the stimulated recall interview. Although Loughran *et al*’s. (2003, 2004) prompts were used during the stimulated recall interview, it still seemed difficult for the lecturers to articulate their knowledge used for teaching. This is shown by each lecturer’s response to the prompt, “what do you intend the students to learn about this idea?” An example is when Mr Moerane mentioned “understand the concept ‘dynamic chemical equilibrium’ using an illustration”. He mentioned, as he did in the pre-CoRe, the concept to be taught and the teaching procedure for the concept and did not mention what he would like to teach the students about the concept. Alternatively one of the concepts mentioned by Mr Dhlamini is ‘The link to Le Châtelier’s Principle’. He did not say what the link was and how it is linked to Le Châtelier’s Principle and what he would like to teach the students about that link. Unlike the elaborated CoRe, where responses to only three of the prompts were represented, all of the prompts in the reflective CoRe had responses. Since the questions were directly asked, in Mr Moeranes’ reflective CoRe, some of the responses to the prompts in the pre- CoRe were the same, other prompts had more or less information than the prompts in the pre-CoRe. The same response is shown in the prompts, “why is it important for students to know this?” and “what else do you

know about this idea (that you do not intend student to know yet)?”

In Mr Moerane’s pre-CoRe the response to “why is it important for students to know this?” is:

- *To assist them to understand equilibrium ionisation. It has a strong link with acids and bases particularly dissociation of acids and bases;*  
and in the reflective CoRe the response is:
- *To assist them to understand equilibrium ionisation and dissociation of acids and bases.*

In the pre-CoRe the response to “what else do you know about this idea (that you do not intend student to know yet)?” is:

- *Equilibrium ionisation and dissociation of acids and bases;*  
and in the reflective CoRe the response is:
- *Equilibrium ionisation and dissociation of acids and bases;*
- *Practical application of Chemical equilibrium in industrial processes;*
- *Advanced calculations; and*
- *The heterogeneous and homogeneous equilibrium with the health sciences students.*

For the fifth prompt which has been used as an example in the previous two sections four more elements were added as reflected in table 4.4 below. The following represents a section of Mr Moerane’s Reflective CoRe:

PROMPT	REFLECTIVE CoRe
<b>5. Knowledge about students' thinking which influences your teaching of this idea.</b>	<ul style="list-style-type: none"> <li>• They have a vague idea that equilibrium has something to do with balance.</li> <li>• They are unable to tell the difference between static and dynamic equilibrium.</li> <li>• They believe that once equilibrium has been reached, nothing else happens.</li> <li>• They perceive the equilibrium to be static rather than dynamic.</li> </ul>

**Table 4.4 A section of Mr Moerane's reflective CoRe.**

#### **4.11 MR MOERANE AND MR DHLAMINI'S COMPOSITE CoRe**

After looking at the limited reflective and elaborated CoRe and thinking about Mr Moerane and Mr Dhlamini's teaching, especially considering their teaching strategies, the researcher realised that there were basically two ideas in their teaching. They were the dynamic versus static equilibrium and the extent of the reaction. These two ideas were the guiding principle around the construction of the composite CoRe. These ideas are referred to as "big ideas" by Loughran *et al.* (2003; 2004). "Big ideas" refer to science ideas that the teacher/s see as crucial for students to develop their understanding of the topic (Loughran *et al.*, 2006). Extracting the "big ideas" also formed the basis of Loughran *et al.*'s. (2003; 2004) CoRe. Considering the overlap, especially with Mr Moerane's CoRe, the composite CoRe therefore represents a construction based on the extraction of the "big ideas" and a consideration of the pre-CoRe, elaborated CoRe and reflective CoRe for each lecturer. This is a more comprehensive CoRe as it represents all the information about the content considered by the two lecturers and is taken from all the data sources. It also elaborates and reflects the type of knowledge that the two lecturers consider before, during and after teaching the topic, chemical equilibrium. Table 4.6 shows the

composite CoRe.

## **4.12 CONSTRUCTION OF THE COMPOSITE CoRe (CONTENT OF CoRe)**

The content of the composite CoRe (or the responses to the prompts) provides a more comprehensive overview of how Mr Moerane and Mr Dhlamini approach the teaching of chemical equilibrium, what content they consider as being important to teach, the reasons for the approach, how they teach and why they use the strategies they have used. The responses to each of the prompts will be analysed and discussed in detail in the next section, see table 4.6.

### **4.12.1 What do you intend the students to learn about this idea?**

The data collected during the observation was a useful source for the information included in this prompt. Loughran *et al.* (2006) refer to this information which is commonly viewed as important for students to learn in order to understand a topic as ‘main ideas’. The ‘main ideas’ must not be confused with the “big ideas”. These ‘main ideas’ provide a framework for the topic, although the order in which they are taught may differ from one lecturer to the other. The ‘main ideas’ in the composite CoRe are the same as those in the elaborated CoRe as they are taken from the observations and they tell one more about what the lecturer actually wanted to teach the student about a concept rather than just listing the concept as in the pre-CoRe and the reflective CoRe. When scrutinising the information included in the responses to prompt one in table 4.6, there is a misconception about equal amounts at equilibrium. Given all the other things that Mr Dhlamini said, this was clearly a mistake on his part. He did not really believe that. Table 4.5 below represents Mr Moerane’s and Mr Dhlamini’s ‘main ideas’. In table 4.5 **B** signifies both, **D** Mr Dhlamini’s and **M** Mr Moerane’s main ideas.

Dynamic versus Static Equilibrium	Extent of reaction
<ul style="list-style-type: none"> <li>• ‘Equilibrium’ means balanced. <b>(B)</b></li> <li>• The rate of the forward reaction equals the rate of the reverse reaction when ‘dynamic equilibrium is reached’. <b>(B)</b></li> <li>• The three conditions for equilibrium to be reached are: a closed system, the amount of reactant and product remains constant at equilibrium and the rate of the forward reaction equals rate of the reverse reaction. <b>(B)</b></li> <li>• Difference between ‘static equilibrium’ and ‘dynamic equilibrium’. <b>(B)</b></li> <li>• A reversible reaction is a reaction where equal amounts of reactant and product are left at the end of the reaction.<b>(D)</b></li> <li>• The forward is represented by the one arrow (→) and the reverse reaction is represented by the other arrow (←).<b>(D)</b></li> </ul>	<ul style="list-style-type: none"> <li>• A closed system is one from which reactants or molecules do not escape. <b>(B)</b></li> <li>• When a system in equilibrium undergoes a change of conditions (temperature, pressure and concentration) the composition of the system will change in a way which counteracts the disturbance (Le Châtelier’s Principle). <b>(B)</b></li> <li>• Calculation of <math>K_c</math> for homogeneous equilibrium involves substances in the same phase.<b>(M)</b></li> <li>• Calculation of <math>K_c</math> for heterogeneous equilibrium only involves the gases.<b>(M)</b></li> <li>• Interpretation of <math>K_c</math> for small and large values .<b>(M)</b></li> <li>• For the equation <math display="block">aA + bB \rightleftharpoons cC + dD</math> <math>K_c</math> expression is given by: <math display="block">\frac{[D]^d [C]^c}{[A]^a [B]^b}</math> <b>(D)</b></li> <li>• The effect of an increase in temperature pressure and concentration a chemical reaction in equilibrium.<b>(D)</b></li> <li>• The effect of a catalyst on the equilibrium of a chemical reaction.<b>(D)</b></li> </ul>

**Table 4.5 Mr Moerane and Mr Dhlamini’s ‘main ideas’**

#### **4.12.2 Why it is important for students to know this?**

From the above table 4.5, the two “big ideas” emerge, the dynamic versus static equilibrium and the extent of the reaction. According to Loughran *et al.* (2004), the ‘big ideas’ are the headings of the CoRe (why it is important for the students to know this) which illustrates the reason for the way in which the topic is conceptualized. Mr Moerane’s reason for teaching / learning the concept ‘dynamic chemical equilibrium’

and related concepts, which has been identified as being important for students to learn to explain dissociation and ionization of acids, was consistent in all the data sources. Mr Dhlamini was only able to articulate this in the stimulated recall interview hence it has only been included in the reflective and composite CoRe.

#### **4.12.3 What else you know about this idea (that you do not intend student to know yet)?**

The third prompt also contributes to the framing of the topic. As much as the main ideas tell us what the lecturer intends the students to learn, “What else you know about this idea, that you do not intend the student to know yet?” highlights what the lecturer does not intend the students to learn when teaching chemical equilibrium. Both Mr Dhlamini and Mr Moerane knew about the more advanced calculations involving  $K_{sp}$ ,  $K_a$ ,  $K_b$  and  $Q_c$  which would be encountered in chemical equilibrium, acid–base equilibria and common–ion effect later on in the first year curriculum. Initially in the interview before the lesson, Mr Moerane was able to respond to this, whereas Mr Dhlamini did not even mention it. The composite CoRe shows that both lecturers suggested that at access level, these ideas were too advanced for the student and that the basic concepts and ideas in chemical equilibrium need to be developed before the students can be exposed to more advanced ideas linked to chemical equilibrium.

#### **4.12.4 What difficulties/limitations are connected with teaching this idea?**

Chemical equilibrium has been identified as one of the most difficult topics to teach and learn (Bergquist and Heikkinen, 1990; Tyson, Treagust and Bucat, 1999). This difficulty has been confirmed through research into misconceptions held by students and teachers in the topic chemical equilibrium. Some of the difficulties highlighted by Mr Moerane are similar to those identified by Vilakazi (1990). These include:

- Identification of reversible reactions.

- Inability to visualise simultaneity of forward and reverse reactions in the same container and
- Confusion with the idea of closed systems.

Other difficulties identified by both Mr Moerane and Mr Dhlamini in the Composite CoRe are general difficulties which pose a challenge when teaching in higher education institutions. They include problems with:

- Language.
- Students' lack of prerequisite knowledge and
- linking microscopic to macroscopic understanding.

This also shows how much the lecturer knows about the teaching of the topic by considering the students difficulties or limitations associated with the topic and how it would influence teaching of the topic. Mr Moerane was aware of the students' difficulties/limitations associated with closed systems, reversible reactions and of forward and reverse reactions happening at the same time. Mr Dhlamini however did not show any awareness of these problems until the stimulated recall or review session. He mentioned the following in response to the above prompt:

*'Students' view of a chemical reaction. The representation of a chemical reaction as we know it is  $A+B \rightarrow C+D$ . For the students  $A+B$  is in one container and  $C+D$  is in another container'.*

Although both Mr Moerane and Mr Dhlamini did not show equal awareness of the difficulties/limitations of the concepts associated with chemical equilibrium, they were both aware that practical demonstrations could have possibly enhanced students understanding. They were also both aware that the students had poor background knowledge and that background knowledge forms an integral part of teaching and learning chemical equilibrium.



#### **4.12.5 What knowledge about students' thinking influences your teaching of this idea?**

For both lecturers it seemed as if it was the ideas students held about dynamic equilibrium and other related topics such as acids and bases and gases that further influenced their teaching of the “big ideas”. Mr Moerane’s knowledge of students that also influence the teaching of these “big ideas” is related to a common misconception where students view equilibrium as being a balance of amounts, i.e. amount of reactants is equal to the amount of products rather than the rate at which products are formed, is equal to the rate at which reactants are formed. This links up with Mr Moerane’s other point where he highlights that the students cannot differentiate between ‘dynamic’ and ‘static’, and that they believe that once equilibrium has been reached nothing further happens. PCK manifested itself in the way that Mr Moerane addressed this problem. He used two diagrams to show equilibrium at a lower and a higher temperature, each showing a different level of solution. He showed both diagrams on the same transparency (see Appendix E).

#### **4.12.6 What other factors that influence your teaching of this idea ?**

This prompt further highlighted that each idea showed a very important resource, the textbook which is used in the teaching of chemical equilibrium. Both Mr Moerane and Mr Dhlamini used various textbooks when teaching chemical equilibrium. The type of textbooks used by Mr Moerane showed more understanding of resources needed to deal with the challenges and considerations for the students when teaching chemical equilibrium. Mr Moerane used textbooks from Grade 12 through to first year university to prepare for his lessons on chemical equilibrium. Although both lecturers used a common textbook approach of phase equilibrium to introduce dynamic equilibrium, the way in which Mr Moerane used it to recognize and respond to the difficulty associated with understanding dynamic equilibrium was an indication of PCK with respect to the topic.

Mr Moerane's teaching procedure manifested itself in an overall strategy which is discussed in greater detail in chapter 6. Mr Dhlamini's teaching procedure manifested itself differently to Mr Moerane's, in a more fragmented way and this is also discussed in chapter 6. In table 4.6 below **B** signifies both, **D** Mr Dhlamini and **M** Mr Moerane.

Dynamic vs Static Equilibrium	Extent of reaction
<b>Prompt 1 What do you intend the students to learn about this idea?</b>	
<ul style="list-style-type: none"> <li>• The concept 'dynamic chemical equilibrium' vs static. <b>(B)</b></li> <li>• Reversible reactions. <b>(B)</b></li> <li>• The concept 'chemical equilibrium'. <b>(B)</b></li> <li>• Rates of reversible reactions and factors influencing these. <b>(B)</b></li> <li>• Difference between closed and open systems <b>(B)</b></li> <li>• Heterogeneous and homogeneous equilibrium. <b>(M)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Expression for equilibrium constant, <math>K_c</math>. <b>(B)</b></li> <li>• Homogeneous and heterogeneous equilibrium <b>(M)</b></li> <li>• Le Chatelier's Principle. <b>(B)</b></li> <li>• Conditions and factors affecting chemical Equilibrium. <b>(B)</b></li> <li>• Interpretation of graphs <b>(B)</b>.</li> </ul>
<b>Prompt 2 Why it is important for students to know this?</b>	
<ul style="list-style-type: none"> <li>• To understand future topics such as rates of reaction. <b>(B)</b></li> <li>• To understand extent of reaction <b>(B)</b></li> <li>• The Concepts in 1. above are the key concepts to understanding chemical equilibrium <b>(B)</b>.</li> <li>• It aids them in understanding other linked topics in related courses (such as Biology) <b>(D)</b>.</li> <li>• Chemical equilibrium is linked to what they would do in research should they decide to pursue a career in chemistry <b>(D)</b>.</li> </ul>	<ul style="list-style-type: none"> <li>• To understand future topics such as ionisation and dissociation of acids and bases. <b>(B)</b></li> </ul>

Dynamic vs Static Equilibrium	Extent of reaction
<b>Prompt 3 What else do you know about this idea (that you do not intend students to know yet)?</b>	
<ul style="list-style-type: none"> <li>• Equilibrium ionisation and dissociation of acids and bases (<b>B</b>).</li> <li>• Open, closed and isolated systems (<b>B</b>)</li> </ul>	<ul style="list-style-type: none"> <li>• Application of chemical equilibrium to industrial processes (<b>D</b>)</li> <li>• Advanced calculations (<b>D</b>)</li> <li>• In depth knowledge of heat associated with chemical reactions (<b>B</b>).</li> <li>• The common-ion effect (<b>M</b>).</li> </ul>
<b>Prompt 4 What difficulties/limitations are connected with teaching this idea?</b>	
<ul style="list-style-type: none"> <li>• Lack of prerequisite knowledge for understanding chemical equilibrium (<b>B</b>).</li> <li>• Difficulties visualising the microscopic picture of the processes in a chemical reaction (<b>M</b>).</li> <li>• Identify reversible and non-reversible reactions (<b>M</b>).</li> <li>• Difficult scientific concept (<b>M</b>).</li> <li>• Gauging the level of prior knowledge and linking it to the level at which you want to introduce the material (<b>D</b>).</li> <li>• Acids and bases and aqueous chemistry need to be taught first as the distinction between amount of substance and concentration becomes clearer (<b>D</b>).</li> </ul>	
<b>Prompt 5 What knowledge about students' thinking influences your teaching of this idea?</b>	
<ul style="list-style-type: none"> <li>• Vague idea that equilibrium is connected to balance (<b>B</b>).</li> <li>• Unable to differentiate between static and dynamic equilibrium (<b>B</b>).</li> <li>• Once equilibrium has been reached, nothing else happens (<b>B</b>).</li> <li>• They encountered phase equilibrium earlier (<b>B</b>)</li> <li>• Forward and reverse reaction happening simultaneously in the same container (<b>D</b>).</li> <li>• Closed system in chemistry (<b>B</b>)</li> </ul>	<ul style="list-style-type: none"> <li>• Do not know about chemical reactions, balancing of equations, homogeneous and heterogeneous mixtures, and heat of reactions, solutions and crystallisation (<b>B</b>).</li> <li>• Misconceptions e.g. mistaking equilibrium constant for concentration (<b>D</b>).</li> <li>• The students' knowledge of acids and bases (dissociation, acid-base reactions) (<b>D</b>).</li> </ul>

Dynamic vs Static Equilibrium	Extent of reaction
<ul style="list-style-type: none"> <li>• Equilibrium as static rather than dynamic <b>(B)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Exothermic and endothermic reactions (which are taught in rates of chemical reactions) and their graphs <b>(D)</b>.</li> <li>• Students' view the reactants and products of chemical reactions as unrelated (the reactants seem to exist in one container and the products in another) <b>(D)</b>.</li> </ul>
<b>Prompt 6 What other factors that influence your teaching of this idea?</b>	
<ul style="list-style-type: none"> <li>• Profile of the student in an access programme <b>(B)</b>.</li> <li>• Nature of materials the students have been exposed to <b>(B)</b></li> <li>• Prescribed student guide for Access Chemistry <b>(B)</b>.</li> <li>• Poor command of language <b>(B)</b>.</li> <li>• Lack of background in practical work <b>(B)</b></li> <li>• The access chemistry materials, Chemistry the Central Science by Brown <i>et al.</i>, general concepts in chemistry and other general chemistry textbooks <b>(D)</b>.</li> <li>• The outcomes for Access chemistry as well as the outcomes for the topic “chemical equilibrium” <b>(B)</b>.</li> <li>• The lecturer's own understanding of the topic <b>(D)</b>.</li> <li>• The lecturer's tutoring experience <b>(D)</b>.</li> </ul>	
<b>Prompt 7 Teaching procedures (and particular reasons for using these to engage with this idea).</b>	
<ul style="list-style-type: none"> <li>• Using static equilibrium and phase equilibrium to explain chemical equilibrium <b>(B)</b></li> <li>• Diagrams to illustrate dynamic phase equilibrium. <b>(B)</b></li> <li>• Saturated solutions to further elucidate the concept of dynamic equilibrium <b>(M)</b></li> <li>• Using diagrams, transparencies and graphs to explain concepts. <b>(B)</b></li> </ul>	<ul style="list-style-type: none"> <li>• Students solve problems in front of Class <b>(B)</b></li> <li>• equations to develop and explain <math>K_c</math> using examples with very large and very small <math>K_c</math> <b>(M)</b></li> <li>• Using activities with equations to develop and explain <math>K_c</math> expression and <math>K_c</math> constant. <b>(B)</b></li> <li>• Activities that develop problem solving.</li> </ul>

Dynamic vs Static Equilibrium	Extent of reaction
<ul style="list-style-type: none"> <li>• Using static equilibrium in Physics and module 1(phase equilibrium) to explain chemical equilibrium. (B)</li> <li>• Using activities which develop problem solving in chemical equilibrium (B)</li> </ul>	(B)

**Table 4.6 Mr Moerane and Mr Dhlamini’s Composite CoRe**

### 4.13 CONCLUSION

The researcher tends to agree with Loughran *et al.* (2003) that PaP-eRs offer one way of capturing the holistic nature and complexity of PCK, more than is possible in the CoRe. PaP-eRs have the capacity to represent a “narrative whole” and function to explain in text what one knows in action as a teacher. Mr Moerane’s and Mr Dhlamini’s PaP-eRs were intended to give the reader the following:

- a clear idea as to what happened in the classroom
- the lecturers’ pedagogical reasoning (Loughran, 2004) and,
- what could have been done differently.

It is also the first two of these elements which bring the CoRe to life.

However, from the composite CoRe, it can be concluded that the CoRe was more of a developmental process which started off merely as extracting concepts from the PaP-eRs. Once it became clear that it could have been used as an interview instrument, it was used to refine and validate information. The process of refinement and validation involved both the researcher and the lecturer. As mentioned in the introduction, the information documented in the CoRe has been developed from all the data sources and direct responses of the lecturers to the prompts. The following chapter analyses the data which has been included in the PaP-eRs and composite CoRe.

## **CHAPTER 5: ANALYSIS OF RESULTS**

### **5.1 INTRODUCTION**

In this chapter, the data included in the CoRe and the two PaP-eRs will be analysed under two main headings, the overall teaching strategy and the representations. In the discussion the researcher will examine the visible evidence in the classroom, viz. strategies, representations, analogies, etc. to show how the following four types of knowledge are integrated using a model of PCK from Rollnick *et al.* (2007) discussed in chapter two:

- Knowledge of subject matter (the content to be taught as outlined in the curriculum);
- Knowledge of students (student's prior knowledge which is a prerequisite to understanding the topic and of their context);
- General pedagogical knowledge, which encompasses knowledge of learners and learning, classroom management, curriculum and instruction (Geddis and Wood 1997); and
- Knowledge of context (the educator's context, the environmental context and the educational context).

### **5.2 ANALYSIS OF RESEARCH DATA**

As mentioned previously, the CoRe and the two PaP-eRs (one for Mr Moerane and one for Mr Dhlamini), were used to capture and portray the PCK of the two lecturers in this study. Both the above artifacts were developed in an attempt to articulate tacit knowledge by linking it to practice. The CoRe and the PaP-eRs were modified from those developed by Loughran *et al.* (2004). The PaP-eRs were a narrative account of the lecturers' practice and the CoRe focuses on the teachers' understanding of those aspects that represent and shape the content, and contribute to the content-specific

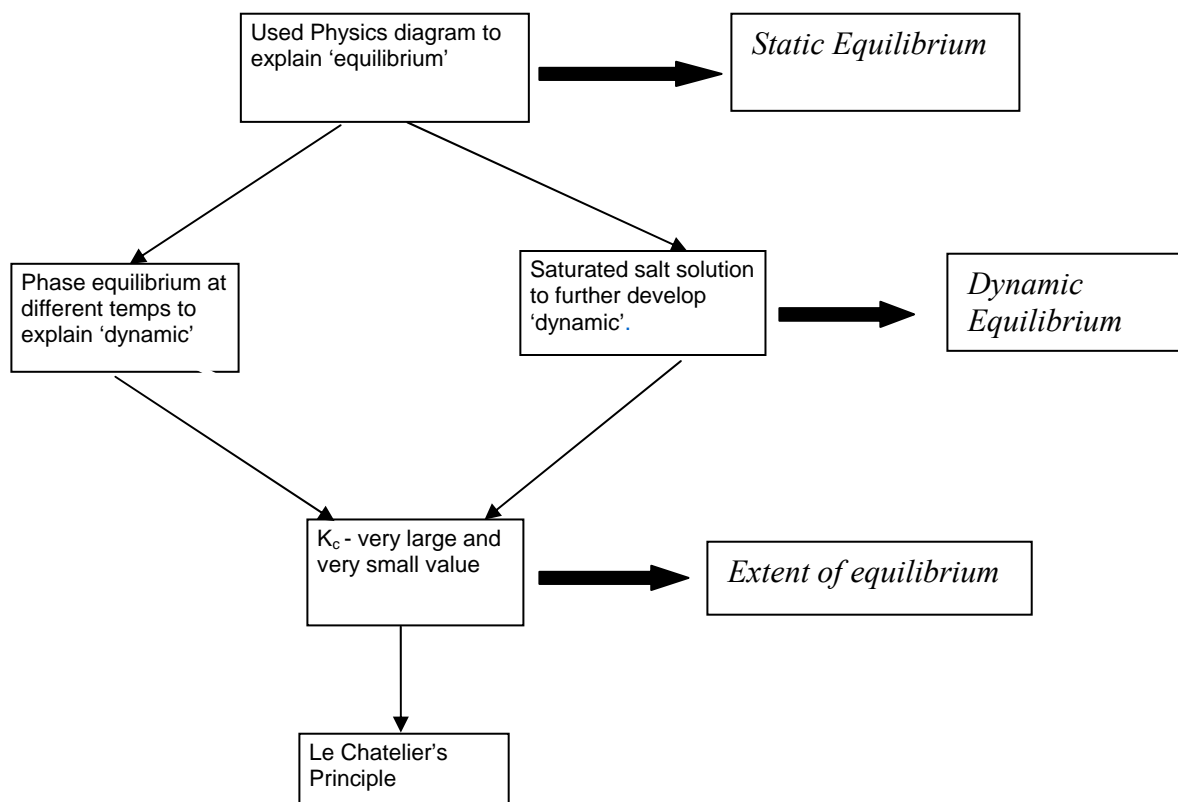
nature of PCK. The CoRe summarises and integrates aspects of the content and practice that guide teaching while the PaP-eRs bring to life the ideas in the CoRe.

The CoRe and the PaP-eRs were also used as methodological tools to assist with the analysis of data and hence represent the construction of what was observed in the lessons taught by the lecturers in the case study. The lecturers involved could not be described as expert teachers, as there was concern about the extent of the content knowledge in the case of the experienced teacher and the inexperience of the expert shown during his teaching practice. The CoRes and PaPeRs were constructed through analysis of pre- and post-instruction interviews, audiotapes, field notes taken during observations, written reflections, stimulated recall and videotapes. The two lecturers' teaching strategies will be discussed, followed by an analysis of the findings in the study.

### **5.3. OVERALL STRATEGY**

Mr Moerane had a better developed overall strategy than Mr Dhlamini for teaching the topic. However, during the pre-interview, he was unable to articulate his overall strategy which had been exposed during his lesson. He merely provided a list of concepts when asked what he intended learners to learn (see Mr Moerane's pre-CoRe in Appendix C). He described his teaching strategy as teaching topics in a particular order in which examples would be used to consolidate the work. He also referred to the use of the overhead projector to illustrate phase equilibrium, and suggested the use of exercises for the students. He could give no reason for the teaching order chosen, other than that it would work out well and that he would work from the known to the unknown. He indicated that he would begin with the students' existing background knowledge, using phase equilibrium, a common point of departure. In a rare moment of clarity he carefully outlined his sequence of concepts which formed part of his strategy. During observation of his teaching he followed this plan. From phase equilibrium, he expressed the intention of moving on to principles of chemical

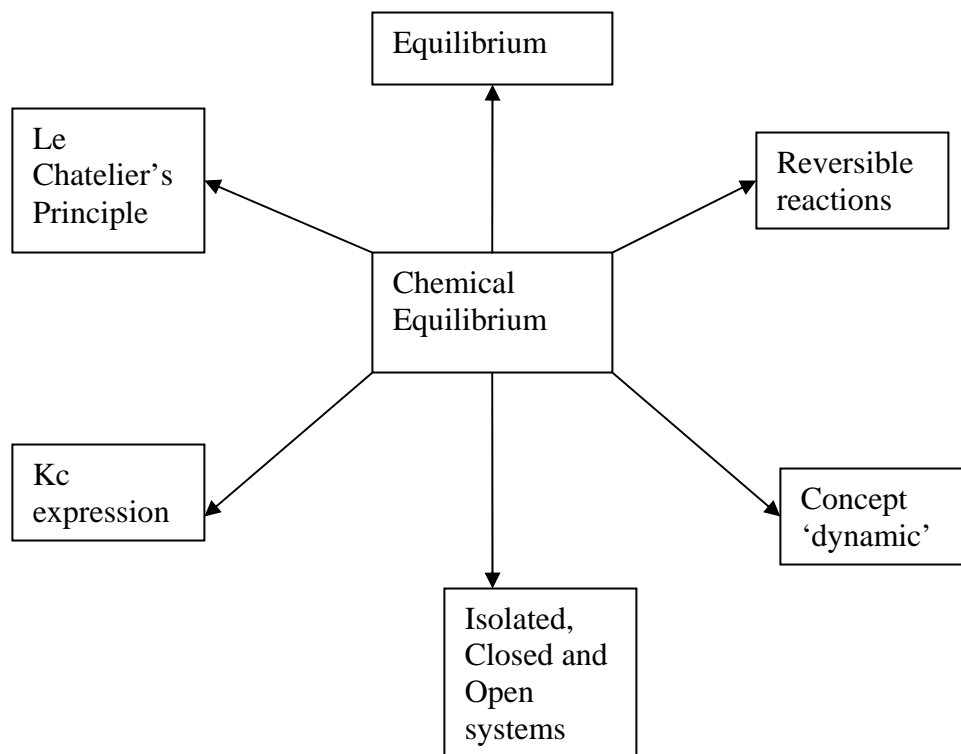
equilibrium. He said that he would include the equilibrium expression and value of  $K_c$  in the 1<sup>st</sup> session and that by interpreting it, the basis for Le Chatelier's principle would have been laid. He said that he wanted the students to have the basics before he spoke about equilibrium of ionisation and dissociation of acids and bases. During his lesson he followed this sequence through which translated into his overall strategy. This was informed by a logical flow of material that he had explicitly thought through and prepared. Most of the strategy focussed on the development of 'dynamic equilibrium'. He took great care in developing this idea. Mr Moerane used this overall strategy during his lesson to achieve the objectives that he outlined to the students at the beginning of the lesson. It seems to have worked well. An overall strategy, which works, can only be developed as a result of teaching experience and can be attributed to a well developed PCK. One of the advantages that Mr Moerane had was his experience in teaching. Figure 5.1 shows Mr Moerane's overall strategy.



**Fig. 5.1: Mr Moerane's overall strategy**



In his overall approach, Mr Moerane taught the concepts related to chemical equilibrium, in the order shown in the representation. Mr Moerane's strategy was well conceived in terms of his understanding of the logic and progression of the content, and his students' current understanding. His choice of examples was simple and took into account the students' previous experience. For example, his choice of phase equilibrium, though a common one used in many text books, took into account the fact that they had studied phase changes earlier in the course. The simplicity of the system also makes it a good starting point as only one type of molecule is involved. He also added a further example of dynamic equilibrium, a saturated salt solution, an example which took the students a step closer to a chemical reaction. In his treatment of  $K_c$ , he used examples with very large and very small values, using extreme case reasoning as anchors to illustrate the concept (Clement *et al.*, 1989) and ended with a fairly traditional treatment of Le Chatelier's principle. Analysis of data related to Mr Dhlamini did not produce an overall strategy, as had been the case of Mr Moerane. He also did not reveal any overall strategy during his interview, although in his classroom practice he did try to use an approach which he thought would work for him. His teaching approach came across as being a focus more on concepts (content) of chemical equilibrium which needed to be taught to the students. The approach appeared to be fragmented, which suggested that he had no overall strategy. In his reflections, Mr Dhlamini agreed that he viewed the topic chemical equilibrium as a number of isolated concepts. Figure 5.2 outlines Mr Dhlamini's teaching strategy.



**Fig. 5.2: Mr Dhlamini's overall teaching strategy**

Mr Dhlamini discussed the term equilibrium very differently to Mr Moerane although Mr Dhlamini also used static equilibrium in physics (an object resting on a table) as an example. He first split the word equilibrium into 'equi' and 'libra' and then discussed different examples of equilibrium which included the physics example. He also used phase equilibrium to discuss the concept dynamic but did not depict it using different representations like Mr Moerane did. The equilibrium constant,  $K_c$  was discussed using relevant examples. Finally he discussed Le Chatelier's principle. In his discussion on the effect of pressure he included the gas laws which are not included in the access chemistry curriculum. This demonstrated a lack of curricular saliency which will be discussed in 5.7.

## 5.4 ANALOGIES AND REPRESENTATIONS

Various analogies and representations are used to promote conceptual understanding in chemistry. These analogies and representations are included in the way Shulman (1986) characterized PCK.

### 5.4.1 Use of balanced forces diagram from physics to represent equilibrium

Both Mr Moerane and Mr Dhlamini used the example of balanced forces holding an object in equilibrium from physics to explain the concept 'equilibrium' although the equilibrium in physics is static, rather than dynamic. They drew on the learner's prior knowledge of equilibrium which was gained from foundation physics.

Mr Moerane used the diagram shown in Figure 5.3 to show the students an example of equilibrium.



**Fig.5.3. Mr Moerane's example of equilibrium**

The lecturer agreed with the students when they told him that the arrows represented upward and downward forces. He used the arrows to show that there were two equal forces which held the object in equilibrium. He said that the equilibrium was static as the object is at rest (held in equilibrium) because of two opposing forces.

On the other hand, Mr Dhlamini placed a chalkboard duster on the table and explained that there were two equal forces acting, an upward force of the table on the duster and a downward force of the duster on the table. He said that this was one of

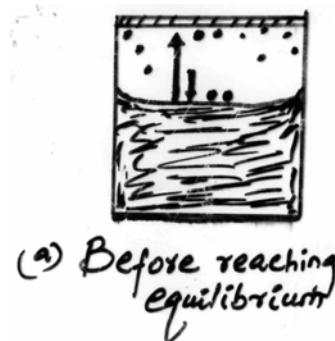
the examples of equilibrium. On the transparency he had a note about the balanced forces where the resultant is zero and also pointed out the static nature of this equilibrium.

#### **5.4.2 Using phase equilibrium to show the ‘dynamic’ nature of equilibrium**

It is very common to use phase equilibrium to introduce the concept 'dynamic' when discussing equilibrium. This is evident in most textbooks which include the topic chemical equilibrium, e.g. Physical Science 10 (Brink and Jones, 1989). Phase equilibrium is so widely used when discussing equilibrium as many students can identify with the concept as it involves an everyday occurrence of heating water in a container using heat and closing the container with a lid. It is also a familiar ‘physical example’ which the students encounter throughout their schooling (from primary school through to senior secondary school). Both lecturers, Mr Moerane and Mr Dhlamini, also used phase equilibrium to explain the concept 'dynamic', but each lecturer used it very differently. By using this approach the lecturers’ were able to draw on and integrate student’s prior knowledge of phase equilibrium.

During the pre-lesson interview, Mr Moerane spoke about phase equilibrium being ‘a common point of departure’, which he also used in his lesson. Mr Moerane's planning, teaching experience and his PCK, which has developed with experience, was evident, particularly during the phase equilibrium discussion. He used phase equilibrium effectively. He used it to address two topic specific issues, ‘dynamic’ and ‘rate’. These two concepts are very abstract and difficult for students to conceptualise. They are also crucial to understanding chemical equilibrium. The concept ‘dynamic’ was developed in a systematic way. He used the heating of a liquid substance as an example. Although he said that most reactions are reversible, he did not pursue further discussion on this concept. He used three diagrams (a, b, c) to represent the system at a lower temperature before reaching equilibrium (a); at the

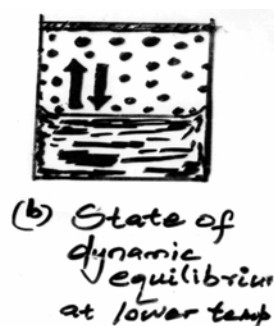
same temperature after reaching equilibrium (b); and then at a higher temperature after equilibrium had been re-established (c).



**Fig. 5. 4. Mr Moerane's first diagram taken from the transparency to show the system before reaching dynamic equilibrium.**

He used the diagram (a) to show the students that initially the rate at which evaporation takes place is greater than the rate at which condensation takes place. This is represented by the arrows which differ in length. The long arrow was used to represent the rate of evaporation and the short arrow to represent the rate of condensation before equilibrium. Although the arrows do not necessarily show the dynamic nature of the reaction he used, the length of the arrows to show 'rate'. He used the microscopic particles to represent the vapour above the liquid and a macroscopic representation (a continuous model) with a meniscus to show the liquid and the level of the liquid. The fact that the level of the liquid remained the same made it seem as if there is no longer any movement on a macroscopic level. Microscopically there was something happening with the liquid as there were particles leaving and entering the container. He also represented the vapour as being particles which leave the liquid.

Immediately after that he used the two other representations (b, c) to show the system at equilibrium at the lower temperature (b) and then at a higher temperature (c).



**Fig.5.5. Mr Moerane's second diagram taken from the transparency to show the system at Phase Equilibrium.**

The second diagram Fig.5.5. was used to show the students the state of equilibrium at the same temperature as (a). The opposing arrows of equal length show that the rate at which evaporation takes place is equal to the rate at which condensation takes place. The vapour was also represented using particles. The diagram was used to show that the change is happening at a microscopic level and macroscopically there are no observable changes.

It is also very common in textbooks and while teaching, to use diagrams which illustrate the liquid as being continuous and the water vapour particulate. Mr Moerane's diagrams also illustrated the continuous versus the particulate. A third diagram, Fig.5.6., was introduced to show the effects of increasing the temperature.



**Fig.5.6. Mr Moerane's third diagram taken from the transparency show the system at Phase Equilibrium at a higher temperature.**

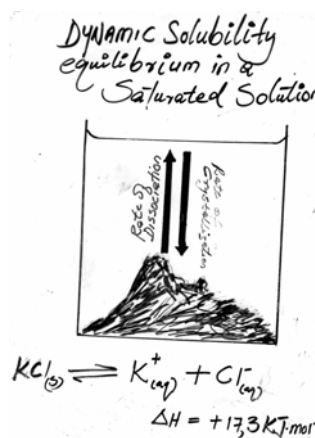
It represented a lower level of liquid to show that an increase in temperature increased the rate of the reaction hence an increase in evaporation. He described it as a ‘shift to the right’, meaning that more vapour was present and also mentioned that the reaction was endothermic. This diagram was also used to show that a new equilibrium had been established, at a higher temperature. The opposing arrows of equal length were again used to show that the rate at which evaporation was taking place is equal to the rate at which condensation was taking place. This represented equal rates of the ‘opposing processes’. It was also strategic for Mr Moerane to draw the diagrams next to each other on the transparency so that a comparison of the liquid levels could be made. The difference in the level of the liquid in container (b) and (c) showed that the rates are equal but not the amounts of liquid and vapour, which is a common misconception in equilibrium. Again the microscopic structure of vapour was highlighted showing particles above the liquid. He described the equilibrium represented in the diagram as ‘phase equilibrium of liquid vaporisation’. The diagram was also used to show that reducing the heat will favour the condensation of vapour which he described as ‘shift to the left’. He also highlighted that the reverse reaction would be exothermic.

All three diagrams represented the closed system, which was mentioned by Mr Moerane later in the lesson, as one of the conditions for equilibrium. In this way he introduced the concept ‘closed system’ very subtly without expanding on it. It seemed that at this point the students only needed to know that the reaction was taking place in a closed system, which is represented by the closed container in the diagram.

### **5.4.3 Using a saturated salt solution to further develop the idea ‘dynamic’**

After using the phase equilibrium, Mr Moerane continued to develop the idea of ‘dynamic’ by using a simple example of a saturated salt solution which is the equilibrium between an undissolved solute and dissolved solution. Buell and Bradley

(1972) described this as an extremely good example of ‘dynamic equilibrium’. The representation and equation showed a reaction which is more ‘chemical’ than phase equilibrium which was ‘physical’.



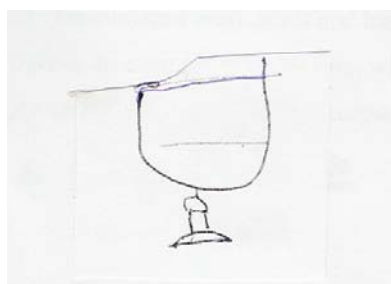
**Fig.5.7. Mr Moerane’s diagram to show a saturated salt solution at solubility equilibrium.**

This example was used to logically develop the idea that the concept ‘dynamic’ has to do with rates. It represented two opposing processes, dissociation and crystallization, which were shown by the arrows of equal length. He said that at equilibrium, the rate at which dissociation happens is equal to the rate at which crystallization happens. The reaction that he chose is described by some chemistry experts as a chemical reaction. He said that he chose it purposely, as the students were familiar with this reaction.

Mr Dhlamini, in comparison, did not mention the use of phase equilibrium as a point of departure and he also did not begin with the discussion of phase equilibrium. Mr Dhlamini used phase equilibrium to introduce the concept ‘dynamic’ after he had discussed reversible reactions. The everyday meaning of dynamic as movement or motion and as active or energetic was used to develop an understanding of purely the word ‘dynamic’. In the context of equilibrium, the lecturer highlighted that he was going to use phase equilibrium to develop an understanding of the term dynamic. Mr



Dhlamini's diagram of phase equilibrium, to develop the idea of dynamic equilibrium did not show the detail which Mr Moerane's did. It only showed that the container contained liquid which was heated using a Bunsen burner and that the container was closed. Mr Dhlamini did not really develop the concept of dynamic equilibrium by using a detailed description and discussion of phase equilibrium. He merely used phase equilibrium as a reminder to show the idea of dynamic equilibrium. Mr Dhlamini used the following diagram to show the heating of water in a beaker:

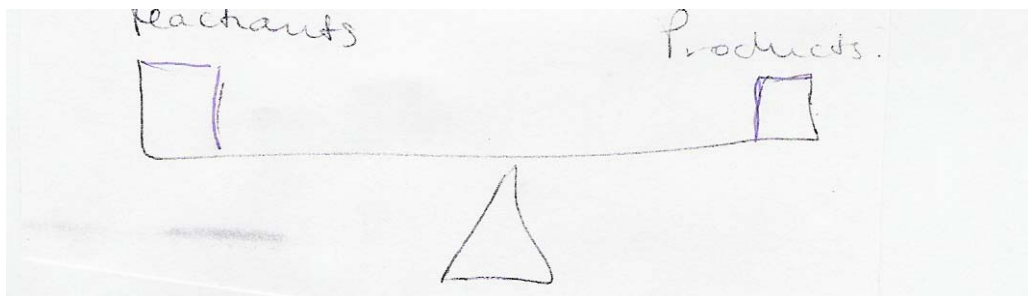


**Fig.5.8. Mr Dhlamini's diagram to show the system at phase equilibrium.**

He also used the diagram to discuss what would happen macroscopically if the liquid was heated. He agreed with the students that initially they would notice a change in the level. He said that once a dynamic equilibrium with regard to phase change is reached, there would be no changes macroscopically. He said that there would be changes at a microscopic level. The discussion was very brief.

#### **5.4.4 Using a pair of measuring scales to show the concept 'equilibrium'**

Initially Mr Dhlamini used a pair of measuring scales to develop the idea of balanced when discussing equilibrium. The diagram showed two quantities A on the left hand side and B on the right hand side. He used the following diagram to show that the two quantities were equal and therefore balanced:

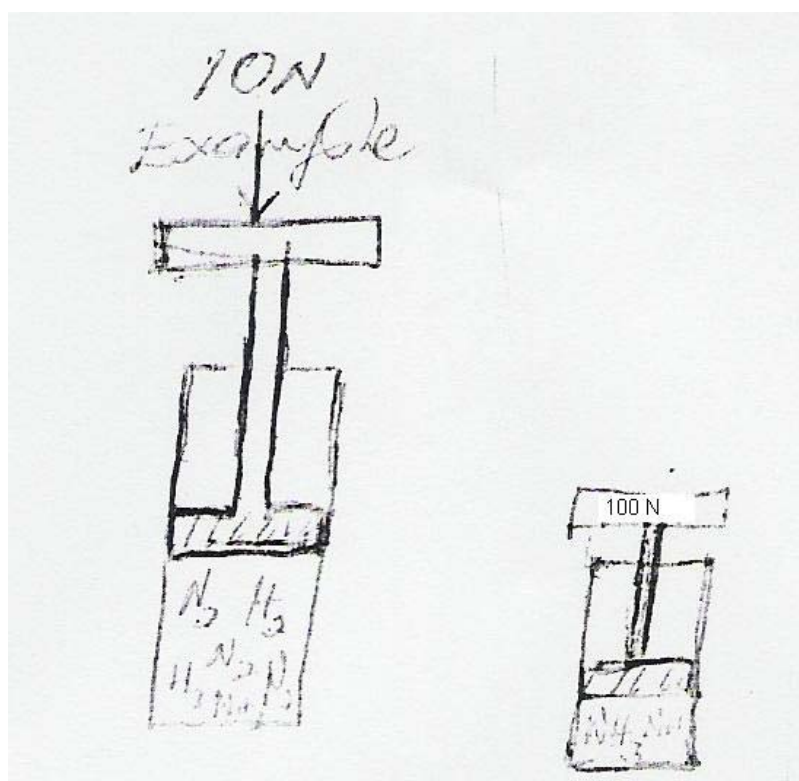


**Fig.5.9. Mr Dhlamini's diagram to show 'equilibrium'.**

He also used the two quantities to show that there were two opposing processes. The representation was used very effectively, but could have created the impression that when a chemical reaction is in equilibrium, the amount of reactant is equal to the amount of product. Perhaps at a later stage in the lesson, this could have been pointed out to the students. He also mentioned in his discussion that there are two opposing processes that must be balanced or equalised. This entrenches the misconception of equal amounts on each side even further, though it does not appear that Mr Dhlamini thought this.

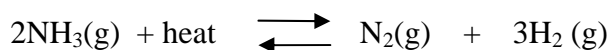
#### **5.4.5 Using a piston to show the effect of changing pressure on equilibrium**

Using a piston or a syringe is a common textbook approach used to explain the effect of changing the pressure on the equilibrium of a reaction. Mr Moerane used this approach very effectively. He used the following two diagrams in Figure 5.9 to show the effect of pressure on equilibrium:



**Fig.5.10. Mr Moerane's chalkboard drawing of a syringe to show the effect of change in pressure on equilibrium.**

Mr Moerane also used the following equation together with Figure 5.10 to explain the effect of changing pressure on equilibrium



**Fig.5.11. Mr Moerane's chalkboard equation used to explain the effect of change in pressure on equilibrium.**

Figure 5.10 and 5.11 were both drawn on the chalkboard to discuss the effect that changing the pressure would have on the equilibrium of a chemical reaction. It was effective in that the students were familiar with the reverse equation used to represent the Haber process. Using a familiar chemical equation which involves only gases, he could show the students that there are 4 molecules of nitrogen and hydrogen on the right hand side (products) and 2 molecules of ammonia on the left hand side

(reactants). The students had also covered the stoichiometrical calculation where they are expected to make deductions using the coefficients from the balanced chemical equations. The number of moles of gas could therefore be used to show the difference in volume between the reactants and the products. The molar volume of the reactants is shown to be greater than that of the products. The reversible arrows are used to show that the reaction is reversible.

The linking of the equation in Figure 5.11 to the diagram in Figure 5.10 was also very important in assisting the students understanding of the relationship between volume and pressure. This was shown by the following conversation between Mr Moerane and the students during consolidation of the discussion on the effect of pressure taken from the field notes which were written during the observation of Mr Moerane's lesson:

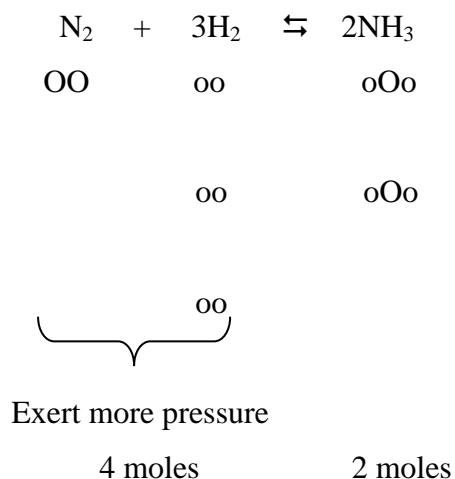
*Mr Moerane: 'If  $p$  were increased based on the equation. Before we answer it let us look at a single illustration. A vessel with a piston. It has a syringe to move the piston up and down . Which volume does it favour?'*

*Student reponse: 'It favours the small volume'.*

The students are also familiar with the use of a syringe to show an increase or decrease in pressure. The use of the first diagram to show that the force exerted per unit area is 10N and the large volume is occupied by six molecules of gas and the second diagram to show that the force per unit area was increased to 100N and occupied by the smaller volume, 2  $\text{NH}_3$  molecules, also worked quite well. It demonstrated the changes in pressure and the effect that the changes had on the volume. Although the equation is only representative of the ratio between the molar volume of reactant and product, the use of the representation could be extended to show the students how the spaces are actually occupied by the molecules depending on the volume.

### 5.4.6 Using Boyle's law and the ideal gas law to explain the effect of changing pressure

Mr Dhlamini used Boyle's law and the ideal gas law to explain the effect of change in pressure on the equilibrium of the following chemical reaction:



**Fig 5.12. Mr Dhlamini's chemical equation which he used to explain the effect of changing pressure on equilibrium.**

Mr Dhlamini used the same chemical equation, as Mr Moerane, to discuss this section. He used microscopic representations to show the structure of the reactants and the products. Whether representing these substances microscopically was effective in explaining the effect of pressure on equilibrium, is questionable.

## 5.5 KNOWLEDGE OF STUDENTS

The students who are accepted into the bridging programme have not achieved the minimum requirement to enter the mainstream diplomas, but show a potential to succeed. These students therefore have a certain profile. Both Mr Moerane and Mr Dhlamini were aware of the students' context and their student profile. Mr Moerane

had taught Access Mathematics previously in the programme, and Mr Dhlamini had encountered a similar profile of student during his experience as a tutor in such a programme at another higher education institution.

Mr Moerane's awareness of this was shown during the interview and during the lesson. Initially, in the interview, Mr Moerane said that he considered the type of student when he did his planning. On further probing he said that it meant the profile of students that are accepted into the programme. These students have gaps and deficiencies in skills and knowledge in science. With respect to his approach to teaching, he mentioned that his starting point was determined by the background of the learners and that "he would go back, back, back to fill those gaps". He also said that not everything was familiar to the learners and that they have a shallow understanding. He mentioned that this was part of the context that he spoke about initially in the interview.

The knowledge of student was also evident in Mr Moerane's lesson in his overall teaching strategy, which he referred to in his interview as 'the known to the unknown'. To do this, Mr Moerane drew on his general pedagogical knowledge. He carefully developed concepts using simple examples that learners could identify with and then moved on to the more difficult examples and concepts. The explanation of how his overall strategy developed is discussed at the beginning of this chapter.

Mr Dhlamini's awareness of the learners' context was also evident in the interview. When he spoke about his planning, he mentioned that he takes into consideration the students' understanding of equilibrium. He was also aware of their misconceptions and identified a particular problem with  $K_c$ . Mr Dhlamini also viewed the phrasing of questions relevant to the students as being important.

In his lesson Mr Dhlamini perceived the understanding of certain concepts e.g. the understanding of chemical equilibrium to be important before moving on to the next

concept. This could have adversely affected the development of an overall strategy and the development of certain strategic concepts as this was not the lecturers focus. In his lesson it was evident that he was aware of language difficulties and therefore split the word equilibrium into two, 'equi' and 'libra' in order to explain its meaning. He also realised that the students needed to understand what is meant by 'reversible' and 'closed system'.

## **5.6 PRIOR KNOWLEDGE OF THE STUDENT**

One of the prerequisites for students to enter the programme is high school Physical Science and Mathematics. Students therefore, come in with their own ideas and understanding of science. The prior knowledge therefore has two categories:

- The prior knowledge that the learners have acquired from previous experience and instruction in science; and
- The prerequisite knowledge to facilitate the teaching of the topic, chemical equilibrium.

Both Mr Moerane and Mr Dhlamini were aware of some form of prior knowledge when they prepared and taught this topic. Overall, Mr Moerane knew that the students come in with their own ideas about science and that there is certain prerequisite knowledge required in order to teach the topic chemical equilibrium. In the interview he mentioned that the background knowledge determined his starting point. This meant that he was aware of the students' context, the fact that all students did not have the same background knowledge (common scientific understanding as a result of previous experiences and instruction) and that he would have to address this problem by attempting to first bring the whole class to a level where he could start teaching. With respect to the prerequisite knowledge to teach chemical equilibrium, he realised that some learners have a shallow understanding of this content. As mentioned earlier, he used phase equilibrium, which is a common textbook approach

to explain the concept 'dynamic'. Phase equilibrium had also been discussed in Module One of the Access Chemistry Curriculum.

Mr Dhlamini's knowledge of the learner was evident, when he mentioned that students struggle with the difference between amount and concentration, especially the Health Science students. With respect to his approach to teaching, he mentioned that, the pace of the lesson depended on the learners' response to what was being taught.

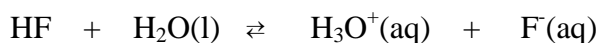
## **5.7 CURRICULAR SALIENCY**

Curricular saliency is another very important aspect of PCK. According to Geddis *et al.* (1993), it highlights the importance and order of various topics relative to the curriculum as a whole. It is specifically addressed in Question 3 of the CoRe prompt, but also emerges in the understanding of what comes before and after the topic in hand. In order to do this, the lecturer needs to know the breadth versus depth coverage (Geddis and Wood, 1997) of the concept or topic. Mr Moerane knew what he needed to expand on, and what not to expand on, as he knew the whole curriculum, as well as related topics. As mentioned above, his choice of phase equilibrium as an introduction to the topic was influenced by his knowledge that the students had earlier studied phase change in their chemistry course. But curricular saliency is also powerfully illustrated by what is omitted from the teaching, for example, he kept his description of a closed system simple, not dealing with open, closed and isolated systems as one of his colleagues (a content expert) did. In comparison, Mr Dhlamini went into a discussion of the different types of systems which was not really necessary at that point. He needed to focus more on the closed system which the students need to understand in the context of chemical equilibrium. Mr Moerane also provided a qualitative description of gaseous phase reactions in his treatment of Le Chatelier's principle when explaining the effect of pressure, rather



than resorting to the gas law equations. He used the representation shown in Figure 5.9 for his discussion.

Mr Dhlamini also used gases, but then he went on to discuss it in the context of the Ideal Gas Equation and Boyle's Law, which was not really necessary. All the students need to know about a gas is that at constant temperature an increase in pressure causes a decrease in volume, and vice versa. This assists them in understanding how pressure affects the equilibrium of a reversible chemical reaction. Mr Dhlamini used the following example to discuss the concept of 'reversible reactions':



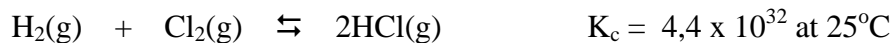
This reaction is not really familiar to the learners. He also used this equation to further develop the concept 'dynamic'. The concept 'closed system' was taught as a separate concept which involved a discussion on isolated and open systems. At bridging level in the context of chemical equilibrium, the students are only required to know about closed systems.

## 5.8 MISCONCEPTIONS

One of the ideas which promote misconceptions is that the equilibrium is said to 'shift to the left or to the right'. Students find it very difficult to understand that the chemical reaction is reversible and that reactants and product all coexist in one container. The word shift seems to promote the idea that there are two containers that exist and that there is some type of movement from one container to the other container.

## 5.9 INTERACTIONS WITH STUDENTS

Since PCK is tacit and inherent, its existence would be manifested in the following representations used, curricular saliency, assessment and classroom interactions (Rollnick *et al.*, 2007) which have been described as teacher knowledge. As mentioned previously, classroom interaction encompasses visible evidence of the teachers understanding of the students, in their interactions with them and the opportunities they create for students to interact with each other. It also focuses on classroom discourse supported by knowledge of the students' context and the discourse of the discipline and how the teacher addresses learners' topic specific difficulties. This was highly evident in Mr Moeranes's treatment of the various concepts in his lessons. Mr Moerane's conceptual treatment of the equilibrium constant,  $K_c$  deserves special mention. He used two simple reactions that were not strictly equilibrium reactions to show the extreme values of  $K_c$ , as shown below:



Interestingly, he made a content error at this point, informing the class that  $K_c$  as a constant did not have units.

Although Mr Dhlamini's knowledge of the learners' context was evident when he mentioned that students struggle with the difference between amount and concentration, he did not particularly address this aspect with a topic specific strategy. Even his classroom discourse did not indicate that he meant to deal with such a problem.

## **5.10 CONCLUSION**

This chapter has shown that as an experienced teacher, Mr Moerane, had a well developed PCK, which he found difficult to articulate during his pre-interview, but displayed in his classroom practice, with his well developed overall teaching strategy. In turn Mr Dhlamini on the other hand being a novice teacher did not have such a well developed PCK, which was evident by his lack of articulation during the interview and the fragmented teaching strategy, although he displayed the potential for his PCK to be developed. The next chapter discusses the overall findings of the study, concludes the study and discusses the recommendations for the study.

## **CHAPTER 6: FINDINGS, CONCLUSION AND RECOMMENDATIONS**

### **6.1 INTRODUCTION**

This chapter discusses the findings, conclusions and recommendations of the investigative study of the PCK of two lecturers, whilst teaching the topic chemical equilibrium. It also provides answers to the research questions which have been documented in chapter 1. This chapter begins with a reflection on the study.

### **6.2 REFLECTION ON THE STUDY**

#### **6.2.1 Modification of CoRe and PaP-eRs**

This particular case study is an analysis of two well documented, teaching case studies (Geddis and Wood, 1997) on the topic chemical equilibrium in a Technikon environment. The case study of Mr Moerane, an experienced teacher, and the second case study of Mr Dhlamini, an inexperienced teacher, made for a good comparison of knowledge about teaching, based on Shulman's (1986) construct, PCK. Since the documenting of this knowledge about teaching posed a great challenge, the researcher used the tools of CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional – experience Repertoires) which were modified from Loughran *et al.* (2003 and 2004) to capture and portray Mr Moerane and Mr Dhlamini's PCK. The CoRe and PaP-eRs were also used as methodological tools, as mentioned in Chapter 5, to assist in the analysis of data, and hence represent a construction of what was observed in the lessons taught by the teachers in aforesaid case studies. This resulted in the development and production of the two teachers' CoRes and PaP-eRs. Although the CoRe and PaP-eRs were developed, using ideas directly from Loughran *et al.* (2003), they were used differently, since the teachers involved in these studies could not be described as expert teachers. Hence a new method of processing CoRes was used.

### 6.2.2 CoRe as a Methodology

The composite CoRe, which is represented in chapter 5, was developed using a three-stage process: the pre-CoRe, elaborated CoRe and the reflective CoRe. This composite CoRe represents the “big ideas” and the content which was considered by the two lecturers for teaching the topic chemical equilibrium and the reason for this consideration. It was necessary to develop the composite CoRe in three stages, pre-CoRe, elaborated CoRe and reflective CoRe since the CoRe prompts were not used during the pre-interview and each of the CoRes at each stage of development was also inadequate to represent the PCK as a whole of a particular lecturer. Given the tacit nature of the knowledge of the lecturers it is also likely that had the prompts been used in the pre-interview sessions, the process would still have been necessary. Each stage of development also reflects the data collected, using different data sources. A comparison from the development of the CoRe shows a difference between Mr Dhlamini and Mr Moerane’s pre-CoRe. It showed, that in the pre-interview Mr Moerane was able to articulate the order of the concepts for teaching the topic chemical equilibrium but could not articulate the reasons or the process, whereas Mr Dhlamini could not articulate what concepts he would include for teaching. The composite CoRe, used as the final CoRe, shows a similarity between what Mr Moerane and Mr Dhlamini considered for teaching chemical equilibrium as Mr Dhlamini was able to articulate what he should have considered for teaching, only in the post interview and reflections where the prompts from the CoRe were used. The overall difference between what the two lecturers considered as difficulties/limitations was shown in this CoRe. The ideas documented show that Mr Moerane had a greater overall understanding of the difficulties of the learners than Mr Dhlamini did. This could be linked to Mr Moerane’s teaching experience. The teaching procedures section also shows that Mr Moerane had a better developed overall teaching strategy. We need to keep in mind that this CoRe was also developed from all the data sources including the lesson. The development of one CoRe represented a way to portray two teachers, one an experienced practitioner and the other, a content specialist. The fact that it can be used for both teachers implies that it

might be a useful resource for training in-service teachers. This highlights an important finding that the CoRe is flexible in that it can be modified and used to represent the PCK of any teacher.

### **6.2.3 PaP-eRs**

The PaP-eRs which were also used to represent the lecturers' PCK were also developed from the pre-interview, the classroom observation of the lessons taught on chemical equilibrium, the post interview using the prompts from the CoRe as well as the written reflections. The PaP-eRs served as a rich insight into Mr Moerane and Mr Dhlamini's teaching practice. It was very difficult to draw any conclusion from Mr Dhlamini's pre-CoRe about his subject matter knowledge, but the PaP-eR allowed the researcher to draw conclusions about this knowledge which could be confirmed during the stimulated recall session after the lessons had been taught. A comparison of Mr Moerane and Mr Dhlamini's PaP-eRs revealed interesting findings about their PCK from the overall strategies and representations used during the lessons and provided a rich description of their practice.

### **6.2.4 Teaching strategies**

Using the CoRe and PaP-eRs the researcher was able to construct a representation of an overall strategy for Mr Moerane which was informed by a logical flow of content and she was able to construct a fragmented teaching strategy for Mr Dhlamini. A comparison of the two teaching strategies revealed a better developed PCK on the part of Mr Moerane, which could be attributed to his teaching experience. This was evident in the analogies, representations and examples which he used and how he used them in his teaching practice. The "big ideas" were also made more visible from the elucidation of Mr Moerane's teaching strategy. In the case of Mr Dhlamini, there was no distinct overall strategy. His overall teaching of chemical equilibrium came across as very fragmented.

### **6.3 COMPARISON OF REPRESENTATIONS, EXAMPLES AND ANALOGIES USED IN THE TEACHING STRATEGIES**

Although there were many similarities in the way in which certain concepts were introduced during the lesson, there were also marked differences in the effectiveness of the use of these concepts by Mr Moerane and Mr Dhlamini. The following extract shows the similarities:

- Both Mr Dhlamini and Mr Moerane separated the terms, “dynamic”, “chemical” and “equilibrium” and tried to explain them separately before explaining the concept as a whole;
- Both used analogies from physics to explain the word “equilibrium”;
- Both used the idea of phase equilibrium in a closed system to introduce the idea of a dynamic equilibrium, but used it differently; and
- Both simply added the word, “chemical” to the understanding of dynamic equilibrium that they had built on up to this point, not elucidating any further what the distinction might be.

The differences were fundamental. Although both lecturers used phase equilibrium to explain the concept ‘dynamic’, they used it very differently. Mr Moerane’s use of phase equilibrium fitted in with his overall strategy teaching the topic chemical equilibrium. Mr Dhlamini’s use of phase equilibrium was part of his strategy to teach ‘dynamic’ as a concept which needs to be taught when teaching the topic, chemical equilibrium.

The use of phase equilibrium is a common textbook approach to teach dynamic equilibrium. This highlights the resources used by both Mr Moerane and Mr Dhlamini. They both used general chemistry textbooks, but Mr Moerane’s use of the diagrams on a transparency to show dynamic equilibrium at different temperatures showed the link to Physical Science 10 (Brink and Jones, 1989), a matric textbook.

He was therefore able to use these diagrams to move from what was familiar to the students (phase equilibrium) to what was unfamiliar to them (dynamic chemical equilibrium). The order in which the concepts were presented by Mr Dhlamini is also the order in which the concepts are presented in general chemistry textbooks. The examples which were done as exercises in the lesson were also common textbook examples. Once the lecturers had developed the concepts, especially in Mr Moerane's case, it is almost as if there was no link to the exercises done. There was a void as the lecturers moved to an algorithmic way of answering the questions. This is one of the problems which pose a great challenge, the move from a more conceptual way of understanding to an algorithmic way where there is a recipe to solve problems rather than reasoning it out to get to the solution.

#### **6.4 INTERPRETATION OF TEACHING STRATEGIES USING A MODEL OF PCK**

The most important aspect under investigation in this particular research study is the lecturers' PCK with respect to teaching chemical equilibrium. PCK is considered to be an amalgamated product of the following four domains of teacher knowledge identified by Rollnick *et al.* (2007) in the consolidated model of PCK:

- Knowledge of subject matter;
- Knowledge of students;
- General pedagogical knowledge; and
- Knowledge of context.

The consideration of a part of or all four fundamental domains of teacher knowledge was shown in Mr Moerane and Mr Dhlamini's overall teaching strategy. The overall strategies of Mr Moerane and Mr Dhlamini, and the representations that they used in teaching, were also a manifestation of the extent of their PCK. Both lecturers integrated the different types of knowledge, but the way in which it was manifested in the overall strategy and the representations, showed a difference in the extent of the



development of the various knowledge domains in their PCK. Mr Moerane, being the more experienced teacher, seemed to have a better developed PCK than Mr Dhlamini. Although there were a few content problems with Mr Moerane's presentation of the lesson, he displayed ability in terms of his overall strategy, as can be seen in the previous chapter. This could be attributed to his teaching experience. Mr Dhlamini, on the other hand, had very few content problems, but his overall strategy was not as well developed strategies, curricular saliency and topic specific strategies, amongst others which are visible in the classroom.

In terms of the tailored model (Rollnick *et al.*, 2008) represented in Figure 2.1, Mr Moerane displayed a highly developed PCK in terms of what could be observed in his teaching (upper part of the tailored model for PCK) yet his articulation of the strategy in the interview did not reveal the underlying domains of knowledge which can be read into such an approach. This raises a question about the extent to which teacher knowledge is explicitly articulated and leads to the belief that the knowledge is tacit.

An important aspect of Mr Moerane's practice was his sound subject matter knowledge which he combined with knowledge of his students and the teaching context to produce the manifestations observed above. His knowledge of student misconceptions on equilibrium had not been informed by a reading of the literature, as he has not studied science education at a post graduate level. Rather his awareness stemmed from his previous experience with similar students and had become part of his craft knowledge. His representations arose from a study of common texts and his own creativity in extending them.

Since there was gap created by his general pedagogical knowledge (shown in the lower part of the tailored model for PCK), Mr Dhlamini displayed a poorly developed PCK, compared to Mr Moerane. This was shown by the fragmented teaching strategy and the types of representations he used. This also affirms the idea that PCK is the craft of the experienced teacher, and develops with experience and practice.

Mr Moerane also integrated his understanding of curricular saliency in his discussion on closed systems by not even mentioning open and isolated systems which could have complicated the discussion. This provided perspective on the dilemma of breadth versus depth of coverage (Geddis and Wood. 1997) of the curriculum. This was in contrast to Mr Dhlamini who was not aware of the concept of curricular saliency. Mr Dhlamini included open and isolated systems when discussing closed systems.

## **6.5 RESPONSE TO RESEARCH QUESTIONS**

The three research questions and the answers to the questions based on the results in this study are:

1. What is the PCK of the two lecturers with respect to teaching the topic chemical equilibrium?

Mr Moerane had a very well developed PCK whereas Mr Dhlamini had a less developed PCK with respect to teaching Chemical Equilibrium.

2. What differences exist between the two lecturers' PCK with respect to chemical equilibrium?

The difference between the two lecturers PCK was shown by their overall strategies which were developed from their teaching. Mr Moerane had a very well developed overall strategy which showed a logical flow of ideas. This showed that he had a better developed PCK than Mr Dhlamini. On the other hand, Mr Dhlamini had a very fragmented teaching strategy which was not informed by a logical flow of ideas. This showed that his PCK was not as well developed as Mr Moerane's.

3. How can we capture and portray the lecturers' PCK with respect to Chemical

## Equilibrium?

It has been shown that the lecturers' PCK can be captured using a modified model of Loughran *et al*'s. (2003) CoRe and PaP-eRs.

Mr Moerane was able to display well developed PCK with his nuanced subject matter knowledge giving him the flexibility to produce innovative approaches when combined with his knowledge of the teaching context, his general pedagogical knowledge and his understanding of the students. However, the tacit nature of Mr Moerane's knowledge, invites further investigation. He has well developed strategies for teaching key sections of the chemistry curriculum. If these are not easy to articulate, then it is only possible to uncover them by observing his lessons. The question is whether awareness on his part of the construct of PCK, together with exposure to metacognitive strategies, would assist him to articulate his tacit knowledge? In an environment where conceptual teaching strategies are the exception rather than the norm, a teacher such as Mr Moerane could serve as a valuable resource in assisting other teachers to develop such approaches. The question is whether this could be done in the absence of adequate subject matter knowledge.

Mr Dhlamini though, did not display a very well developed PCK which was evident during his teaching practice. However, with his sound content knowledge in chemistry and exposure to reflective teaching practice which comes with teaching experience, his PCK could be developed. An insight of both the further education and training and the first year chemistry curriculum could provide a basis to develop his curricular saliency.

The question of whether CoRe and PaP-eRs can be used to represent the PCK of Mr Dhlamini and Mr Moerane has been answered earlier in the discussion as we were able to develop one CoRe and two PaP-eRs. It has also shown that this method of documenting and portraying PCK is highly flexible and adaptable. It can therefore be

used to document and portray PCK of any teacher or lecturer. It is therefore a useful tool to expose teachers and researchers to subject matter knowledge for teaching, which has been documented, although it is viewed widely as being abstract, tacit and difficult to articulate.

## **6.6 LIMITATIONS OF THE STUDY**

In retrospect, after the decision to use CoRe and PaP-eRs to document and portray Mr Dhlamini and Mr Moerane's PCK, the researcher was disappointed that the prompts from the Loughran *et al.* (2004) CoRe had not been used as an interview tool. Furthermore, being a novice at utilising interviews as a research tool to collect data, it was difficult for the researcher to identify opportunities to probe further. The CoRe would have guided and assisted the researcher in focussing on important data which was needed to identify and capture the PCK. It would have also provided an opportunity for Mr Dhlamini and Mr Moerane to articulate their ideas. Since prompt 7 focuses on "teaching procedures", there is a possibility that Mr Moerane would have been able to articulate his teaching strategy better since he would have been probed for reasons for the particular teaching procedure that he followed. Similarly Mr Dhlamini may have been able to articulate the concepts to be taught since he had a lesson plan where his preparation was documented. It can be argued that coupled with the use of the prompts Mr Moerane and Mr Dhlamini might have been made aware of the construct PCK in order to make the tacit knowledge explicit.

## **6.7 CONCLUSION**

The above discussion leads to an awareness of PCK in order to make the tacit explicit. Mr Moerane was able to display more powerful PCK than Mr Dhlamini. However, the tacit nature of Mr Moerane's knowledge invites further investigation. He has well developed strategies for teaching key sections of the chemistry

curriculum. If these are not easy to articulate, then it is only possible to uncover them by observing his lessons. The question is whether awareness on his part of the construct of PCK together with exposure to metacognitive strategies would assist him to articulate his tacit knowledge. In an environment where conceptual teaching strategies are the exception rather than the norm, a teacher such as Mr Moerane could serve as a valuable resource in assisting other teachers to develop such approaches. The question is whether this could be done in the absence of adequate subject matter knowledge.

In the case of Mr Dhlamini who has an excellent subject matter knowledge and a less well developed PCK, exposure to well developed teaching approaches (shown by CoRes and PaP-eRs) and mentoring could prove fruitful in developing his pedagogical skills.

## **6.8 RECOMMENDATIONS**

Research of this nature highlights the need that teachers, who teach in Access Programmes need to have teaching expertise coupled with sound subject matter knowledge. If one of these is not in place it could have implications for the effectiveness and the purpose of access.

Although PCK is a useful construct for all teachers, the challenge is making teachers aware of the construct and encouraging reflective practice. Both Mr Moerane and Mr Dhlamini commented on how being exposed to the CoRe and PaP-eRs gave them an opportunity to reflect on their teaching. The prompts also encouraged them to think differently about their teaching. Research, such as this, highlights the usefulness of CoRes and PaP-eRs in meeting this challenge. CoRes and PaP-eRs could be useful to all in the training of educators, as it could assist in the development of in-service and pre-service teachers. CoRes and PaP-eRs could become resources which could help in-service teachers to reflect on their practice and the pre-service teachers could be

guided in terms of their classroom practice. Although PCK has been characterized as the attribute of a more experienced teacher, the researcher believes that it can become an attribute of the inexperienced teacher by exposing them to documented PCK in the form of CoRes and PaP-eRs. It can be introduced into the formal training of pre-service teachers. It could form part of the subject to which it relates to or be introduced as a stand-alone course. Presently there is a great need for teacher development within the schools and at the level of Access. This could also contribute to improving the expertise of science teaching. Experts within the field of chemistry, who wish to teach at the level of access could also be developed in a similar way.

The use of CoRes and PaP-eRs creates an opportunity for further research into the effective use and impact of this model on the development of the teacher's PCK and an improvement of their teaching practice.

## **APPENDIX A: INTERVIEW SCHEDULE**

TOPIC: Chemical Equilibrium

DURATION: 20mins

INTERVIEWER: Mrs N U Dharsey (Researcher)

INTERVIEWEE: Lecturer1

The purpose of the interview is to find out how the lecturer plans for the lesson on Chemical equilibrium. The questions which appear on the schedule are only possible questions of which some will be used as a guide and others as probes.

1. You are about to teach a lesson, how did you plan for the lesson?
  - 1.1. What aspects of the lesson did you consider?
  - 1.2. What resources did you use?
  - 1.3. Which textbooks in particular?
  - 1.4. Why did you use those particular textbooks?
  - 1.5. What else is important in your planning?
  - 1.6. Why do you consider content as being important?
  - 1.7. What else do you consider?
  - 1.8. What about order in which the concepts are taught?
  - 1.9. Besides order and content what else do you consider as important?

## **APPENDIX B: SAMPLE OF INTERVIEW TRANSCRIPT**

### **LECTURER 1**

#### **METHOD OF DATA COLLECTION: INTERVIEW**

#### **DATE DATA COLLECTED: 4-11-2004**

I-Interviewer

L-lecturer (interviewee)

I: How did you go about planning the lesson you are about to teach?

L: Well in the first place, looking at the type of student. This section is not included in the syllabus, therefore the link with acids and bases, in such a way that my introduction which involves phase equilibrium which is a common point of departure then move on to phase equilibrium, then move on to principles.

L (continued): Include equilibrium expression and value of  $K_c$  indication, 1<sup>st</sup> session. Interpreting it, for Le Châtelier's principle the basis would have been laid.

I: Why are you going to teach the concepts in that particular order?

L: I want them to have the basics because if I talk about equilibrium of ionisation, dissociation of acids and bases. To them not everything is familiar, the context I spoke about.

I: Besides wanting them to have the basics is there any other reason for the order?

L: No particular reason for the order only that it would work out quite well. It is basically the teaching model from the known to the unknown.

I: So what resources did you consult when planning your lesson?

L: Usual textbooks, grade 12... Other material which has been developed.

I: What do you mean by other material which has been developed?

L: Denise's material.



## APPENDIX C: MR MOERANE'S CoRe

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<b>Prompt 1 What do you intend the students to learn about this idea?</b>		
<ul style="list-style-type: none"> <li>• Reversible reactions.</li> <li>• Rates of reversible reactions.</li> <li>• Dynamic equilibrium reverse processes.</li> <li>• Factors influencing the rate of reactions.</li> <li>• Factors influencing the equilibrium of chemical reactions.</li> <li>• Conditions of equilibrium.</li> <li>• Introducing, applying and stating LeChatelier's principle.</li> <li>• Making predictions about equilibrium of chemical reactions.</li> <li>• The <math>K_c</math> expression.</li> <li>• Factors involving <math>K_c</math>.</li> <li>• Chemical equilibrium is a balance.</li> <li>• There is no distinction between static and dynamic equilibrium.</li> </ul>	<ul style="list-style-type: none"> <li>• 'Equilibrium' means balanced.</li> <li>• An object at rest represents a 'static equilibrium' while phase equilibrium represents a 'dynamic equilibrium'.</li> <li>• A closed system is one from which reactants or molecules do not escape.</li> <li>• Once the rate of the forward reaction equals the rate of the reverse reaction a state of 'dynamic equilibrium' has been reached.</li> <li>• There are three conditions for equilibrium to be reached viz. the reaction has to take place in a closed system, the concentrations of reactant and product are constant at equilibrium and the rate of opposing reactions are equal.</li> <li>• When homogeneous equilibrium is reached, the calculation of <math>K_c</math> involves substances in the same phase.</li> <li>• When heterogeneous equilibrium is reached, the calculation of <math>K_c</math> only involves the gases.</li> <li>• When <math>K_c \gg 1</math>, the equilibrium lies to the right and favours the formation of products.</li> <li>• When <math>K_c \ll 1</math>, the equilibrium lies to the left and favours the formation of the reactants.</li> </ul>	<ul style="list-style-type: none"> <li>• Understand the concept 'dynamic chemical equilibrium' using an illustration.</li> <li>• Comprehending equal rates of opposing processes.</li> <li>• They must not confuse constant concentrations with equal concentrations.</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
	<ul style="list-style-type: none"> <li>If a system at equilibrium is disturbed by a change in temperature, pressure or concentration of one of the components, the system will shift its equilibrium position so as to counteract the effect of the disturbance (Le Châtelier's principle).</li> </ul>	
<b>Prompt 2 Why is it important for students to know this?</b>		
<ul style="list-style-type: none"> <li>To assist them to understand equilibrium ionisation.</li> <li>It has a strong link with acids and bases particularly dissociation of acids and bases.</li> </ul>		<ul style="list-style-type: none"> <li>To assist them to understand equilibrium ionisation and dissociation of acids and bases.</li> </ul>
<b>Prompt 3 What else do you know about this idea (that you do not intend student to know yet)?</b>		
<ul style="list-style-type: none"> <li>Equilibrium ionisation and dissociation of acids and bases.</li> </ul>		<ul style="list-style-type: none"> <li>Equilibrium ionisation and dissociation of acids and bases.</li> <li>Practical application of chemical equilibrium in industrial processes.</li> <li>Advanced calculations.</li> <li>The heterogeneous and homogeneous equilibrium with the health sciences students.</li> </ul>
<b>Prompt 4 What difficulties/limitations are connected with teaching this idea?</b>		
<ul style="list-style-type: none"> <li>Poor background knowledge (knowledge of chemical reactions, chemical equations, homogeneous and heterogeneous</li> </ul>		<ul style="list-style-type: none"> <li>Language</li> <li>Difficult scientific concepts.</li> <li>Command of the language of</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<p>mixtures, heat of reactions, solutions and crystallisation) required for understanding chemical equilibrium.</p>		<p>teaching and learning.</p> <ul style="list-style-type: none"> <li>• Poor background knowledge (knowledge of chemical reactions, chemical equations, homogeneous and heterogeneous mixtures, heat of reactions, solutions and crystallisation) required understanding chemical equilibrium.</li> <li>• The students visualising the microscopic picture of the processes (breaking and formation of chemical bonds) in a chemical reaction.</li> <li>• The students find it difficult to identify which reactions are reversible and which are not reversible.</li> <li>• Both the forward and the reverse reaction are happening simultaneously in the same container.</li> <li>• Confusion with a closed system (Chemistry closed system is different to the closed system in physics)</li> <li>• Concepts were not being taught using practical investigations (experiments).</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<b>Prompt 5 What knowledge about students' thinking which influences your teaching of this idea?</b>		
<ul style="list-style-type: none"> <li>The students who enter into the access programme.</li> <li>The profile of the student.</li> </ul>	<ul style="list-style-type: none"> <li>The students' encountered phase equilibrium in module 1 of the chemistry material used by the access students.</li> </ul>	<ul style="list-style-type: none"> <li>They have a vague idea that equilibrium has something to do with balance.</li> <li>They are unable to tell the difference between static and dynamic equilibrium.</li> <li>They believe that once equilibrium has been reached, nothing else happens.</li> <li>They perceive the equilibrium to be static rather than dynamic.</li> </ul>
<b>Prompt 6 Which other factors influence your teaching of this idea?</b>		
<ul style="list-style-type: none"> <li>Aspects of the teaching strategy (teaching factors influencing rates of reactions before factors influencing equilibrium) previously.</li> <li>Consideration of the learner's background knowledge in chemistry.</li> <li>Learners have a shallow understanding of the prerequisite knowledge (e.g. solutions, dissociation and crystallisation) for chemical equilibrium.</li> <li>Part of the idea is a prerequisite for the ionisation and dissociation of acids and</li> </ul>		<ul style="list-style-type: none"> <li>Part of the idea is a prerequisite for the ionisation and dissociation of acids and bases.</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<p>bases.</p> <ul style="list-style-type: none"> <li>• The way in which resources (access chemistry materials, the grade 12 textbooks (Brink and Jones, and Pienaar and Walters), Chemistry the Central Science by Brown <i>et al.</i>, 2006) frame the topic.</li> <li>• Textbooks approach certain topics differently with respect to language, jargon, examples and illustrations used, the order in which the concepts are represented, the concepts used and most importantly the teaching strategies which are sometimes very subtle.</li> <li>• The learner guide for access chemistry which outlines the chemistry curriculum for the year.</li> <li>• The outcomes stipulated in the module.</li> </ul>		
<b>Prompt 7 Teaching procedures (and particular reasons for using these to engage with this idea).</b>		
<ul style="list-style-type: none"> <li>• Using diagrams on transparencies to illustrate the phase equilibrium, exercises and examples.</li> <li>• Oral, individual assessment tasks</li> <li>• There is no particular reason for the order only that it would work out quite well.</li> <li>• The teaching model was from the known to the unknown.</li> </ul>	<ul style="list-style-type: none"> <li>• Using diagrams on transparencies to illustrate the phase equilibrium and dynamic nature of equilibrium.</li> <li>• Using phase equilibrium to show how a closed system and equilibrium work.</li> <li>• Using static equilibrium in physics and module 1 (phase equilibrium) to explain chemical equilibrium.</li> <li>• Used a saturated salt solution to show ‘dynamic equilibrium’.</li> <li>• Using activities with equations to develop and</li> </ul>	<ul style="list-style-type: none"> <li>• Using a ball game to illustrate the concept ‘dynamic chemical equilibrium’.</li> <li>• There is a certain order in which the examples will be used and they will also be used to consolidate.</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
	<p>explain <math>K_c</math> expression and <math>K_c</math> constant.</p> <ul style="list-style-type: none"> <li>• Using static equilibrium in Physics and module 1(phase equilibrium) to explain chemical equilibrium.</li> <li>• Using activities that develop problem solving in chemical equilibrium.</li> </ul>	

## APPENDIX D: MR DHLAMINI'S CoRe

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<b>Prompt 1 What do you intend the students to learn about this idea?</b>		
<ul style="list-style-type: none"> <li>The concept 'chemical equilibrium'.</li> </ul>	<ul style="list-style-type: none"> <li>Equilibrium means equally balanced.</li> <li>Chemical equilibrium involves the equilibrium of chemical reactions.</li> <li>A reversible reaction is a reaction where equal amounts of reactant and product are left at the end of the reaction.</li> <li>The rate of the forward reaction equals the rate of the reverse reaction when equilibrium is reached.</li> <li>The forward (<math>\rightarrow</math>) is represented by the one half arrow and the reverse reaction is represented by the other half arrow (<math>\leftarrow</math>).</li> <li>The conditions of equilibrium can be summarised as: the reaction must take place in a closed system, the system must contain appreciable amounts of products and reactants and the concentration of reactants and products stay constant ( but not equal)</li> <li>A closed system is a system where matter is not exchanged but energy is exchanged</li> <li>For the equation</li> </ul>	<ul style="list-style-type: none"> <li>The difference between: chemical equilibrium and phase equilibrium and the difference between any other equilibrium examples the students might have encountered and chemical equilibrium.</li> <li>The difference between a reaction which goes to completion and one that reaches equilibrium microscopically.</li> <li>Factors that affect the position of chemical equilibrium.</li> <li>The <math>K_c</math> expression.</li> <li>The link to Le Châtelier's principle.</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
	$\underbrace{aA + bB}_{\text{products}} \rightleftharpoons \underbrace{cC + dD}_{\text{reactants}}$ <p>K<sub>c</sub> expression is given by:</p> $[D]^d [C]^c / [A]^a [B]^b$ <ul style="list-style-type: none"> <li>• When a system at equilibrium undergoes a change of conditions (temperature, pressure and concentration) the composition of the system will change in a way which counteracts the disturbance (Le Châtelier's principle).</li> <li>• If the temperature of an endothermic reaction is increased the position of equilibrium would shift to the right hand side and favour the formation of the products. The opposite would hold for an endothermic reaction.</li> <li>• If the pressure is increased, it will favour the side with a smaller volume.</li> <li>• An increase in the concentration of the reactants would favour the forward reaction and the position of equilibrium would lie to the right.</li> <li>• A catalyst does not affect the equilibrium of a chemical reaction.</li> </ul>	



Pre-CoRe	Elaborated CoRe	Reflective CoRe
<b>Prompt 2 Why is it important for students to know this?</b>		
		<ul style="list-style-type: none"> <li>• The concepts in 1. above are the key concepts to understanding chemical equilibrium.</li> <li>• Chemical equilibrium is linked to acids and bases, aqueous chemistry and the mole concept.</li> <li>• To assist them to understand acid – base equilibria.</li> <li>• It aids them in understanding other linked topics in related courses (such as Biology).</li> <li>• Chemical equilibrium is linked to what they would do in research should they decide to pursue a career in chemistry.</li> </ul>
<b>Prompt 3 What else do you know about this idea (that you do not intend student to know yet)?</b>		
		<ul style="list-style-type: none"> <li>• Calculations related to the equilibrium constant.</li> <li>• Advanced calculations e.g. Q, K<sub>sp</sub>.</li> <li>• The heterogeneous and homogeneous equilibrium with the health sciences students.</li> <li>• The common-ion effect.</li> </ul>
<b>Prompt 4 What difficulties/limitations are connected with teaching this idea?</b>		

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<ul style="list-style-type: none"> <li>Students have many misconceptions.</li> <li>One of the problems identified was expressing <math>K_c</math> as concentration rather than a constant.</li> </ul>		<ul style="list-style-type: none"> <li>Gauging the level of prior knowledge and linking it to the level at which you want to introduce the material.</li> <li>Not being able to do practical( so that students can physically observe the changes) and theory simultaneously.</li> <li>Language difficulties hence a focus on the phrasing of tutorial questions relevant to the students.</li> <li>Acids and bases and aqueous chemistry need to be taught first as the distinction between amount of substance and concentration becomes clearer.</li> </ul>
<b>Prompt 5 What knowledge about students' thinking which influences your teaching of this idea?</b>		
<ul style="list-style-type: none"> <li>He considered how he viewed the students' understanding of equilibrium.</li> <li>It was important for the students to understand the concept of 'chemical equilibrium before moving on to other concepts.</li> </ul>	<ul style="list-style-type: none"> <li>Gases (Boyle's Law and the Ideal gas Law).</li> <li>Exothermic and endothermic reactions (which are taught in rates of chemical reactions) and their graphs.</li> </ul>	<ul style="list-style-type: none"> <li>Misconceptions e.g. mistaking equilibrium constant for concentration.</li> <li>The students' knowledge of acids and bases (dissociation, acid-base reactions).</li> <li>Students' view the reactants and products of chemical reactions as unrelated (the reactants seem to exist in one container and the products in another).</li> </ul>
<b>Prompt 6 Which other factors influence your teaching of this idea?</b>		
<ul style="list-style-type: none"> <li>According to the lecturer it would have been good for laboratory work and the teaching the topic to happen concurrently</li> </ul>	<ul style="list-style-type: none"> <li>Chemistry the Central Science by Brown <i>et al.</i> (2006), general concepts in chemistry and other general chemistry textbooks.</li> </ul>	<ul style="list-style-type: none"> <li>The context of the student.</li> <li>The learner guide for access chemistry which outlines the chemistry curriculum</li> </ul>

Pre-CoRe	Elaborated CoRe	Reflective CoRe
<p>as the students could have physically observed changes as a result of the equilibrium being affected.</p> <ul style="list-style-type: none"> <li>• His previous tutoring experience in a similar programme.</li> </ul>		<p>for the year.</p> <ul style="list-style-type: none"> <li>• The outcomes for access chemistry as well as the outcomes for the topic “chemical equilibrium”.</li> <li>• The lecturer’s own understanding of the topic.</li> <li>• The lecturer’s tutoring experience.</li> </ul>
<b>Prompt 7 Teaching procedures (and particular reasons for using these to engage with this idea).</b>		
<ul style="list-style-type: none"> <li>• Using transparencies which were prepared in advance.</li> <li>• Tutorial questions were phrased relevant to the students.</li> </ul>	<ul style="list-style-type: none"> <li>• Using diagrams, transparencies and graphs to explain concepts.</li> <li>• Using activities with equations to develop and explain <math>K_c</math> expression and <math>K_c</math> constant.</li> <li>• Using static equilibrium in Physics and module 1(phase equilibrium) to explain chemical equilibrium.</li> <li>• Using activities which develop problem solving in chemical equilibrium.</li> <li>• Try to convey the logic of the concepts here</li> </ul>	

## **APPENDIX E: MR MOERANE'S PaP-eR**

This PaP-eR focuses on an interview with Mr Moerane in response to the questions on the interview schedule (see annexure A) and Mr Moerane's two lessons teaching the topic, chemical equilibrium to access chemistry students. I have also included the pilot lesson, which he taught to one of his classes.

### **PaP-eR – Chemical Equilibrium**

Mr Moerane is an access chemistry lecturer at the Technikon Witwatersrand (now University of Johannesburg). Although he has a teaching qualification and years of teaching experience, it is the first time that he has taught chemistry in an access programme. He has two years experience teaching access mathematics and therefore has an idea of the profile of the students that we teach in the access programme. He lectures access chemistry to four access engineering classes and one health sciences class.

### **Mr Moerane framing in the interview-preparation of the lesson**

#### **Planning**

With regard to planning, Mr Moerane said that he considers the type of student that he is lecturing in the access chemistry programme. He said that chemical equilibrium is not included in the syllabus and that he was only teaching it because of its link to acids and bases. He said that he used the following resources when he planned the lesson: notes, handouts, the learner guide that is prepared by the facilitator of the access chemistry programme, the modules and further information from reading. He said that he planned in a form of notes in line with the outcome stipulated in the module (see Appendix J). He said that he prepared transparencies with diagrams representing phase equilibrium, exercises and examples that will be used to explain. He said that there is a certain order in which the examples will be used and that they will also be used to consolidate.

### **Approach to teaching**

After Mr Moerane spoke about his planning, he spoke about his approach to teaching. He said that he was flexible because every class is different and the background knowledge was where to start. He said that his starting point was determined by the background knowledge of the learners and that he would go 'back, back, back' to fill those gaps. Mr Moerane believes that every class is unique and therefore he cannot go with a ready-made lesson plan. He said that he prepared in such a way that his introduction, which involved phase equilibrium, was a common point of departure. He said that from phase equilibrium, he moved on to principles of chemical equilibrium. He said that he would include the equilibrium expression and value of  $K_c$  indication in the 1<sup>st</sup> session and that interpreting it, for Le Châtelier's principle, the basis would have been laid. He said that he wanted the students to have the basics before he spoke about equilibrium of ionisation and dissociation of acids and bases.

### **Prior Knowledge**

In his approach to teaching, Mr Moerane suggested that the background of the learner is very important. Upon further probing he said that to them not everything was familiar. In response to the probing question, 'so your starting point is with the learner's background knowledge, what about the prerequisite knowledge for that module?' Mr Moerane said that the students were expected to know about chemical reactions, balancing of equations, homogeneous and heterogeneous mixtures, heat of reactions (not that in depth heat associated with chemical reactions). He said that they also needed to know about solutions, crystallisation so that he could have introduced the concept of equilibrium.

### **Content Knowledge**

After Mr Moerane spoke about his approach to teaching, we spoke about content knowledge. He said that he does consider the content and that at times, some learners have a shallow understanding. He said that he would begin with reversible reactions, before he taught the rates of reversible reactions, which is the

introduction of dynamic equilibrium reverse processes. He said that they would look at the factors influencing the rates of reactions so that they understand the rates. He said that he had done that before. He said that he had discussed Le Châtelier's principle, where they looked at the conditions and that there was an overlap, sometimes, somewhere that facilitated understanding. He said that after he discussed the conditions he would then go to introducing, stating and applying Le Châtelier's principle. He added that the  $K_c$  expression and factors involving the  $K_c$  would be included.

### **Resources**

He said that there was no particular reason for the order only that it would work out quite well and that basically the teaching model from the known to the unknown. He said that textbooks approach certain topics differently and that some used simple language and others used certain jargon and direct examples. He said that he used the usual textbooks and material from grade 12 and S<sub>1</sub> (1st year diploma) textbooks. He also used other material that has been developed for the students in the access chemistry programme which he described as 'Denise's material' as she was the person who developed the material (see Appendix J for a copy of the material). He said, 'I don't go there with a rigid, readymade lesson plan'.

### **Assessment activities**

Mr Moerane said that besides order and content, he likes to assess the progress of the learners. He said that he gives class activities and problems on the board that they can do individually or orally. He said that at times the activities are not planned. Activities are done on demand due to lack of skill, but relevant. The activities, which are done on demand, are taken from a pool of activities available for the topic chemical equilibrium. He said that he used 5 minute, short activities to engage students. He said that basically that is what he considers; after all, chemical equilibrium is a balance. At the beginning he makes a distinction between static and dynamic equilibrium and that's all.

### **Mr Moerane's framing in the classroom**

In his approach to teaching the topic 'chemical equilibrium', he used a definite, deliberate teaching strategy that unfolded or developed as he taught each concept in the order that seemed logical to him. The concept 'equilibrium' was taught using an example from physics, which actually represented a static equilibrium. The lecturer carefully developed the idea of the dynamic nature of equilibrium using phase equilibrium that had been done in module 1 of the curriculum. He also highlighted the effect of temperature on the dynamic equilibrium. The idea of dynamic was further developed by using the dissociation of a saturated solution of KCl that cannot be classified as a definite chemical or physical reaction. The example of a saturated solution was also used to discuss the conditions of equilibrium. In the health sciences classroom the idea of homogeneous and heterogeneous equilibrium was deliberately not discussed, but it was discussed in the engineering class. The  $K_c$  expression and the value were discussed using two contrasting examples of equilibrium, one where the value was large and one where the value was very small. At this point Le Châtelier's principle and its application was discussed looking at the way in which temperature, pressure and concentration affect the dynamic equilibrium of reversible chemical reactions.

### **Introduction to the lesson**

In his lessons Mr Moerane stood in the front of the classroom near the chalkboard and the overhead screen throughout the lessons. He told the class that the researcher would be observing him for the duration of the lesson. He said that they would be discussing the topic, chemical equilibrium. He began his lesson by outlining the lesson on the chalkboard as follows:

### **Chemical Equilibrium**

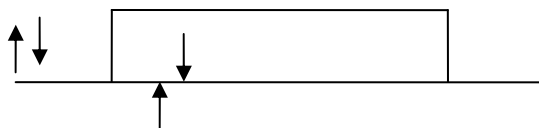
At the end of the lesson you must master the following:

1. Define dynamic equilibrium
2. List conditions of Chemical Equilibrium.
3. Write the Equilibrium expression.
4. Calculate  $K_c$  values.

5. Interpret the  $K_c$  values.

### The concept 'equilibrium' as a balance

He then asked the students whether they understood the meaning of 'equilibrium'. They chorused with the words 'chemically balanced'. One student said that for e.g. if you balance hydrogen and oxygen. The students thought equilibrium means balanced or equal. The lecturer confirmed that it meant just balanced. He drew the following diagram on the chalkboard and asked what it represented:



**Fig. 1: Mr Moerane's example of equilibrium**

The student said that the object was in equilibrium. They also know that the arrows represented upward and downward forces. He elaborated that they were two opposing forces that held the object in equilibrium and that the equilibrium was static.

### The Dynamic nature of equilibrium

Mr Moerane then moved on to explain the dynamic nature of equilibrium using the example of phase equilibrium. The students correctly identified the three phases as solid, liquid and gas. He said that if water were boiled, it would evaporate. He wrote the following on the chalkboard:

*dynamic chemical equilibrium*

*e.g. phase equilibrium*

**Liquid  $\rightleftharpoons$  Vapour**

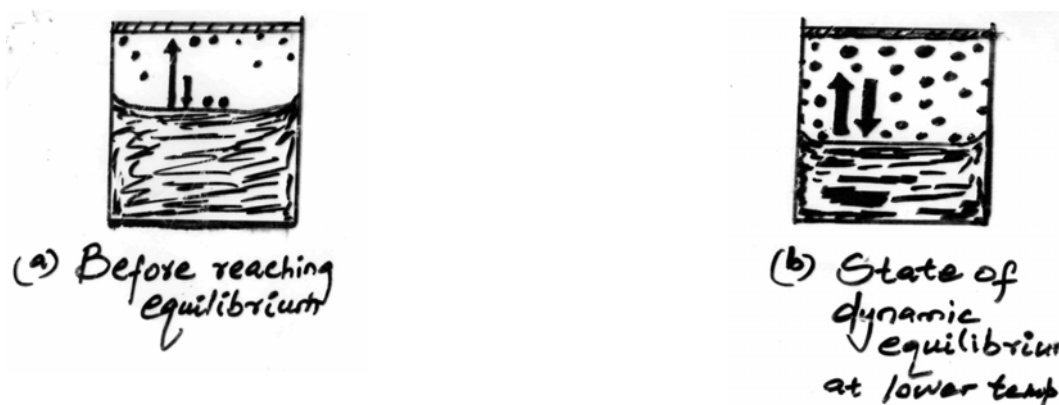
**Fig. 2: Chalkboard notes on phase equilibrium.**



He asked the class what was a closed system. One of the students said that they think the reactant or the molecules do not escape. *The lecturer's body language seemed to endorse the response given by the learner.* The lecturer told the class that most reactions are reversible and that when you heat a liquid there is a point whereby as evaporation takes place, condensation takes place. He wrote the following on the chalkboard:

$$\text{rate at which liquid forms} = \text{rate at which vapour forms}$$

He said it will look like nothing is happening, but we know that the rates are equal. He placed a transparency with the following diagrams on the overhead projector:



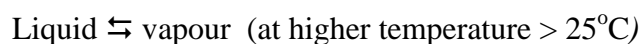
**Fig. 3: Representations of phase equilibrium.**

Referring to diagram a, he explained the following to the class: ‘The water changes to water vapour when heated and therefore we say that the liquid evaporates. Before equilibrium, the rate of the forward reaction is greater than the rate of the reverse reaction. The rate of evaporation is therefore greater than the rate of condensation. The arrows shown in the diagram represent this’.

Referring to diagram a, he said ‘at this stage there are no observable changes. The change happens at a microscopic level. A state of dynamic equilibrium has been established at a lower temperature’.

### The effect of temperature on equilibrium

He then asked the class what would happen if the temperature were increased. A student responded that more water vapour would be formed until all liquid had been transformed to vapour. He agreed with the response and told the class that in the short term this would happen. He said that the forward reaction would be favoured and therefore more vapour would have formed. He wrote the following on the chalkboard:



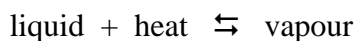
**Fig. 4: Equation representing phase equilibrium.**

He explained further that the forward reaction shifted to the right and that it is an endothermic reaction. He said that the equilibrium would shift to the right until a new equilibrium is re-established at the same temperature that had been raised before. He then referred to the third diagram, shown in Figure 5 below.



**Fig. 5: Representation of phase equilibrium.**

Reminding the class about the closed system, he explained: 'at a higher temperature there is a change in the level of liquid. It will drop. At the new position of equilibrium, there will be more product than reactant. An increase in temperature favours the forward reaction. That is the position. It is phase equilibrium of liquid vaporisation'. He wrote down the following:



**Fig 6: Equation representing phase equilibrium**

He said that reducing temperature will favour the condensation of vapour and that the equilibrium shifts to the left. He said that condensation was exothermic. He pointed to the word equation on the board showing the reverse reaction and said that vaporisation was endothermic. A student posed a question:

*‘Okay the level of the water decreases. How does that happen?  
Surely it needs to be removed’.*

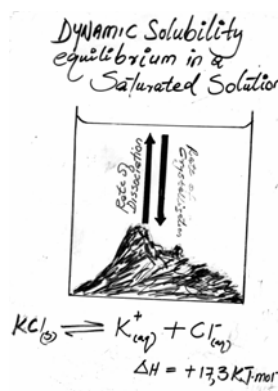
The lecturer answered as follows: ‘The conditions are monitored’ and explains further ‘if you increase the temperature, the pressure must be constant. Monitoring the external factors will not allow the lid to be blown away’. He commented that it was a good question.

### **Using a saturated solution to show dynamic equilibrium**

Mr Moerane asked again what ‘dynamic’ meant. A student responded that it meant the forward reaction equals the reverse reaction. Another student corrected the previous student and said that the rate of the forward reaction equals exactly the rate of the reverse reaction. The lecturer agreed with the correction and added that there are no observable changes and that it seems as if it has stopped. He also said that concentrations are constant at equilibrium. Having established the necessity for a closed system at equilibrium, Mr Moerane established the meaning of the word. He then established the meaning of saturated solution and said ‘So if we take a salt for example based on figures. Proven by means of experimentation. The solubility of KCl at 40°C. We must always state the temperature.

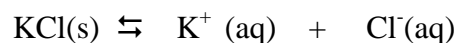
$$\text{Solubility} = 39\text{g}/100\text{g H}_2\text{O}$$

Solubility is the solute /100g of water. Dissolve anything greater than 39g, you are going to have excess solute’. He described that point as the equilibrium point. The lecturer used the following diagram on a transparency to show dynamic equilibrium in a solution.



**Fig. 7: Representation of solubility equilibrium.**

He wrote the following on the chalkboard.



Dissociation vs. crystallisation

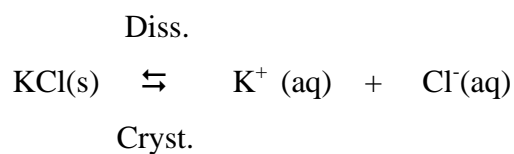
**Fig. 8: Equation of solubility equilibrium.**

Having established the temperature dependence of solubility, he moved on to conditions for equilibrium.

### Conditions for equilibrium

After discussing equilibrium within the context of solubility, he looked at the conditions for equilibrium; using the example. He asked what the conditions were.

The lecturer referred to the following equation (see Figure 8):



at 40°C.

He wrote that the conditions are:

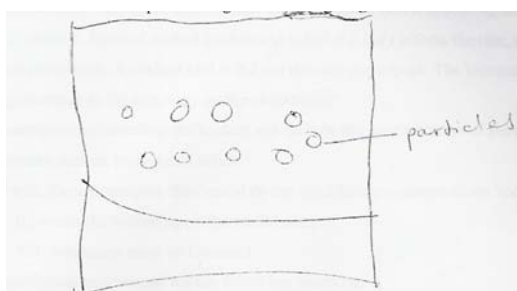
1. The reaction in a closed system.
2. The rate of the opposing processes or reactions is exactly equal.

The lecturer interrupted the discussion on the conditions and asked what it told them about the concentrations of the involved species in equilibrium. A student said that the concentrations are constant. If  $K^+$  and  $Cl^-$  leave the surface, two of those enter the solution. *He seemed to agree with the students' response and continued to write the following:*

3. The concentration of the reactant and products stay constant (the lecturer says he will use the student's word).

The lecturer stressed the importance of the above conditions and asked what it told them. A student responded, 'the closed system of water vapour you said that the rate of the forward reaction = rate of the reverse reaction. But concentrations are not the same'.

The lecturer then said that you use 2 balls between 2 people as an example. A student responded as follows: 'If I say maybe the water evaporates about 20 molecules of vapour at the same time vapour condenses and makes 20 molecules of water. The lecturer commented on the student's response using the following diagram:



**Fig. 9: Representation of evaporation.**

He said that if one particle transformed to a liquid and another transformed to a gas, there were no observable changes. The mathematical relationship between reactants and products would stay constant. Therefore it was logical at equilibrium to represent concentration. We use  $[\ ]$  = concentration.

### **The equilibrium constant ( $K_c$ )**

After the discussion on conditions for equilibrium, the lecturer wrote the following on the chalkboard:

Mathematical relationship

$$[\text{products}] = [\text{K}^+] \times [\text{Cl}^-]$$

**Fig. 11: Mathematical relationship between reactants and products.**

He decided that that was a bad choice and decided to use something general.



$$K_c = [C]^c / [A]^a [B]^b$$

**Fig. 12: A general equation of a chemical reaction in equilibrium and its equilibrium expression.**

He said that the above mathematical relationship remained constant and that  $K_c$  was the equilibrium constant. He posed the following question to the class: ‘what does the  $K_c$  depend on at constant temperature? Take note we are talking about constant temperature’. He wrote the following on the chalkboard:

The  $K_c$  value once equilibrium has been reached

- does not depend on other substances that do not directly participate in the reaction e.g. catalyst.
- Does not have units.

He asked whether a catalyst affected the equilibrium. One of the students said no. The lecturer asked the class what a catalyst was and another student said it speeds up the rate of a chemical reaction. Mr Moerane probed further and asked if it only affects the rate, can we say it does not participate. A student said it did not directly participate. The lecturer seemed satisfied with the response and added the following sentence to the summary on the chalkboard:

- In heterogeneous solutions the  $K_c$  does not include the concentration of pure substances such as liquids and solids.

He said that with those principles, they could do the equilibrium concentrations and expressions. He wrote the following on the chalkboard:

Activity 1 NB: Equations must be balanced.

Write the equilibrium expressions for the following reactions:

1.  $\text{CO}_2(\text{g}) + \text{C}(\text{s}) \rightleftharpoons 2\text{CO}(\text{g})$
2.  $\text{Ag}_2\text{CO}_3(\text{s}) \rightleftharpoons \text{Ag}_2\text{O}(\text{s}) + \text{CO}_2(\text{g})$
3.  $2\text{HgO}(\text{s}) \rightleftharpoons 2\text{Hg}(\text{l}) + \text{O}_2(\text{g})$

At this point, Mr Moerane asked individual students to do examples on the board which they did with his guidance and seemed to enjoy themselves.

### **Homogeneous and heterogeneous equilibrium**

In another lesson, two types of equilibrium were identified as homogeneous and heterogeneous. He drew the following comparison table on the chalkboard eliciting the information from the students:

Homogeneous Equilibrium	Heterogeneous Equilibrium
<p>Involves substances (participating species) in the same phase.</p> <p>E.g.</p> $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$ <p>(Lecturer balanced equation with the students)</p> <p>All species will be considered for the equilibrium constant because they are gases.</p> <p>Equilibrium expression:</p> $K_c = \frac{[\text{product}]}{[\text{reactant}]}$ $= \frac{[\text{NH}_3]^2}{[\text{N}_2] [\text{H}_2]^3}$	<p>Participating species in different phases.</p> <p>E.g.</p> $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ <p>Not all species will be considered for the equilibrium constant, only gases.</p> $K_c = [\text{CO}_2]$

**Table 1: A comparison of homogeneous and heterogeneous equilibrium.**

A student asked the lecturer whether the density of a liquid and solid is not so affected by temperature. He said they were excluded purely because of principle, as it does not depend on the mechanism rather on stoichiometry. He then gave them examples for homework.

### Revision and activities

Having recapped the previous day's lesson, he gave the students the following exercise:

- For the hypothetical reactions:  $\text{A} + \text{B} \rightleftharpoons \text{C}$ , the concentrations at equilibrium are 1,0; 1,5 and 0,5 mol.dm<sup>-3</sup> respectively. Calculate the equilibrium constant for the reaction.

The lecturer asked the class to do the calculation. One student stated that the phases did not matter. The lecturer told the class that they were all gases. The lecturer asked what answer they had obtained. A student said it was 0,33. The



lecturer asked what the  $K_c$  was. The student gave the following response:  
 $[C]/[A][B]$

The lecturer explained how to do the calculation.

He wrote the following on the chalkboard:

$$K_c = [C]/[A][B] = 0,5/1,0 \times 1,5 = 0,33$$

**Fig. 13: Example of calculation of  $K_c$ .**

The lecturer said it was a low value and asked what it said about the value of  $K_c$  and asked what the value  $K_c$  means. A student said that it indicated the number of moles of the reactant. Another student said that it meant the amount of the products is relatively small. The lecturer said that if the concentration at equilibrium of say A and B, more reactant than product therefore a small value. If at equilibrium, there are more products than reactants, the  $K_c$  will be high. He wrote the following example on the chalkboard:

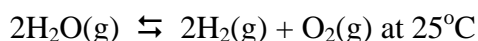
For the reaction



**Fig. 14: An equation of a reaction with its large  $K_c$  value.**

The lecturer asked what conclusions could be made about that reaction. One student said that there was more product formed at that temperature. Another said that there was more product formed at equilibrium. The lecturer said that at equilibrium it lies to the right. That value is so big that the reaction almost runs to completion. There was a negligible amount of product. Students said that the equation was balanced and still the same amount of Hydrogen and Chlorine. The lecturer said that they should look at the relationship. He said the following: ‘The forward reaction occurs almost completely. H and Cl react completely. There is more of the numerator (product) and the denominator (reactant) has less value,

therefore this quotient is going to be big'. A student asked what could be said about the temperature. The lecturer said that the temperature was a condition stated and that conclusions had to be based on the  $K_c$  value. The student said that the  $K_c$  was  $4,4 \times 10^{32}$ . The lecturer said that he did not give the concentration of the reactants at equilibrium. They must make predictions according to  $K_c$  rather than the value in the previous equation. The student commented as follows: 'so a high value would be greater than 1 and a low value would be less than 1'. The lecturer asked the students to look at a reaction where you have water vapour, expecting it to decompose to hydrogen and oxygen. He wrote the reaction on the chalkboard.



$$K_c = 1,1 \times 10^{-81}$$

**Fig. 15: An equation of a reaction with its small  $K_c$  value.**

He said that with the  $K_c$  value for decomposition that was the situation. He wrote the following on the chalkboard:

$$K_c = [\text{H}_2]^2[\text{O}_2]/[\text{H}_2\text{O}]^2$$

**Fig. 16: The equilibrium constant expression for the equation in Fig. 15.**

He said that  $1,1 \times 10^{-81}$  was a small value and asked what the  $K_c$  indicated. A student responded and said that at equilibrium there are more reactants than products. The lecturer told the class that the small value shows that the reaction is impossible and that the equilibrium was extremely further to the left. He continued and said that it was highly unlikely that  $\text{H}_2\text{O}$  vapour could not decompose to  $\text{H}_2$  and  $\text{O}_2$ . He asked what the magnitude of  $K_c$  told them. He showed and read the following on the transparency:

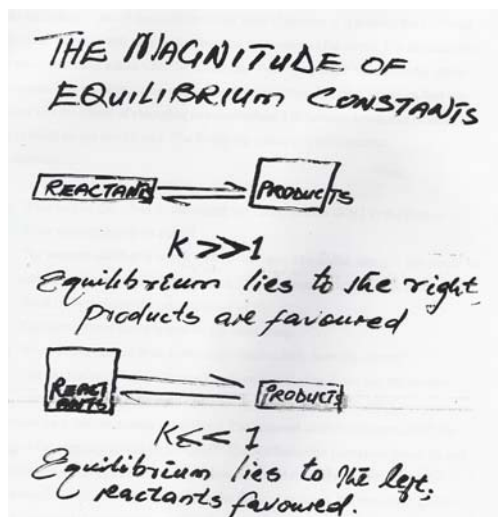


Fig. 17: Representation on the magnitudes of the equilibrium constants.

### Le Châtelier's principle

Mr Moerane revised the three conditions for a system to be at equilibrium as follows.

- (1) Rate (reactants  $\rightarrow$  products) = Rate (products  $\rightarrow$  reactants)  

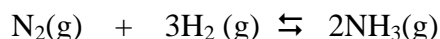
forward
reverse
- (2) Concentrations of the involved substances are constant.
- (3) The reaction must take place in a closed system.

The lecturer displayed a transparency with Le Châtelier's principle and read it to the class. He explained that if any of the conditions changed in the system it would shift so as to undo the change. One of the students asked what if you say it is placing the chemical system under stress; it will turn to the direction to counteract the stress. The lecturer said that it was correct and asked what the conditions were that put the system under stress. The response was pressure, concentration and temperature.

### The effect of changing concentration

The lecturer wrote the above heading (the words in bold) on the chalkboard. The following example was discussed:

In the reaction:



(a) What will be the effect of increasing the concentration of  $\text{N}_2$  in the system?

What prediction will be made?

The lecturer said that it would shift to the right. The added nitrogen gas would be consumed favouring the formation of  $\text{NH}_3$ . The equilibrium will lie to the right.

What if we increase the concentration of  $\text{H}_2$ ? The lecturer said that it would be the same thing.

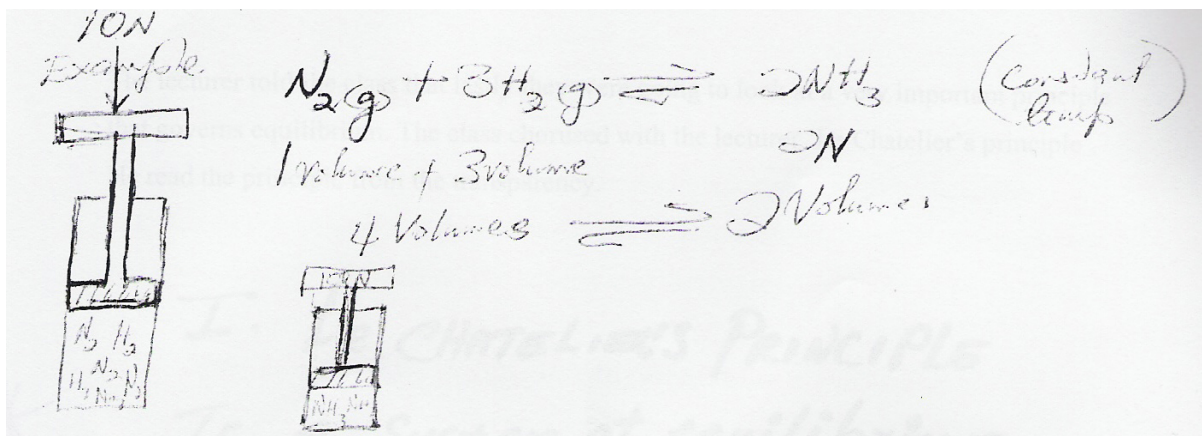
(b) What would happen if we continually remove  $\text{NH}_3$  from the system?

A student said that the forward reaction would slow down and the reverse reaction would be favoured.

The lecturer said that the system is balanced. The removal creates imbalance. Will the forward or the reverse reaction be favoured? The concentration decreased. More  $\text{H}_2$  and  $\text{N}_2$  would react to form product to compensate for the loss. Therefore the rate of the forward reaction will increase encouraging the forward reaction. He explained further that this is applied in industry for maximum production. The forward reaction would be favoured and equilibrium would be established at a new level, a new point. The reaction was inclined to go to completion. The lecturer wrote the following heading on the chalkboard:

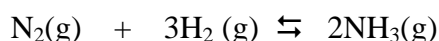
### **The effect of changing pressure**

He asked the students “what is pressure”. A student responded that it was the force per unit area. He drew the following diagram on the chalkboard:



**Fig. 18: Diagrams to show the effect of pressure on equilibrium.**

He said an increase in force exerted would increase the pressure. He told the class that the temperature must be kept constant. Once again he used the example of the formation of ammonia:



We have 1 mole of  $N_2$

Reacting with 3 moles of  $H_2$

To form 2 moles of  $NH_3$

He said that the total number of molar volume is:

1 molar volume + 3 molar volume  $\rightleftharpoons$  2 molar volume

4 mol  $\rightleftharpoons$  2mol

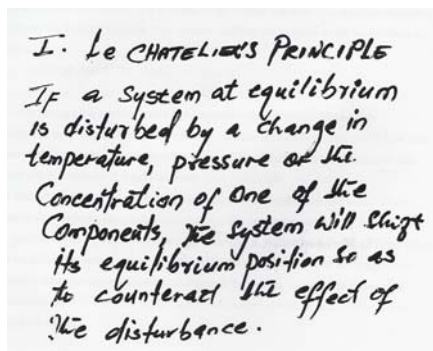
and explained as follows: 'A small volume favours the small number of moles. The system would shift from big to small. Therefore increasing pressure favours small production'. A student asked what happened to temperature during the process as particles are moving in the reaction therefore the temperature does not stay the same. The lecturer responded and said that they were talking about the surrounding conditions and not those within the system. He continued with his explanation and said that  $NH_3$  will be favoured because it is less and that a large amount of  $NH_3$  will be formed because it is favoured. He wrote the following on the chalkboard: Increasing p- small volume (less number of moles)

Decreasing P – bigger volume (greater number of moles)

A student asked if it favours the less mol side can only influence if gases are in the mixture. The lecturer agreed and said that there is no effect if there are no gases.

### Le Châtelier's principle (continued)

He read the following principle from the transparency:



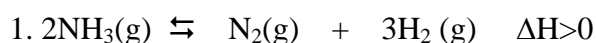
I. Le CHÂTELIER'S PRINCIPLE  
If a system at equilibrium  
is disturbed by a change in  
temperature, pressure or the  
concentration of one of the  
components, the system will shift  
its equilibrium position so as  
to counteract the effect of  
the disturbance.

Fig. 19: Le Châtelier's principle

### The effect of temperature

After presenting Le Châtelier's principle, he went on to discuss the effect of temperature on equilibrium. He said that the day before, he asked two questions about evaporation, dissociation, vaporisation and condensation and that temperature can disturb equilibrium. He told the students to put it in their own words for understanding and that a new position of equilibrium had to be re-established. He said that it would have helped them to make predictions about the reactions conditions. A student commented, 'temperature, pressure and concentration'. The lecturer said that in the case of pressure, the conditions are for gases and that if one changes pressure, the temperature must be constant. The following problem was presented to the class:

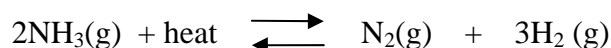
Question



How will matter be redistributed in the above equilibrium if

- (a) the temperature is increased? Explain.

The lecturer pointed to  $\Delta H > 0$  and asked what it meant. One student said that it meant the reaction is endothermic. The lecturer asked which one and said that there was a forward and reverse reaction. The student responded that it was the forward reaction. The lecturer said that the reaction could be rewritten as follows:



He read through the question and emphasised that change would cause a new equilibrium to be established. He also said that an increase in temperature causes an increase in heat that is one of the reactants. One of the students said that an increase in temperature would disturb the equilibrium and it would therefore shift to the right. The lecturer said that it would favour the reaction that absorbs heat and asked which reaction absorbs heat. The student said that it is the forward reaction. The lecturer said that the equilibrium would be displaced to the right. A student asked whether there would ever be a situation where it would be less (referred to the products) if the temperature increased. The lecturer wrote on the chalkboard:

Increasing temperature favours the forward reaction. At the new equilibrium position there would be more of  $\text{N}_2(\text{g})$  and  $\text{H}_2(\text{g})$  than  $\text{NH}_3(\text{g})$ .

He discussed it further with the class using Figure 18 and wrote the following on the chalkboard:

*Increasing pressure favours the reverse reaction, in other words the production of  $\text{NH}_3$ . Equilibrium therefore shifts or lies to the left. There is more of  $\text{NH}_3(\text{g})$  at new equilibrium position than  $\text{H}_2$  and  $\text{N}_2$  together.*

He told the class to put it in the way they understood it. A student asked whether it was the same when  $\text{N}_2$  and  $\text{H}_2$  were put under pressure. The lecturer said yes, it was like the reverse equation. The lecturer told them that lastly the concentration would be covered. He asked what would happen if the concentration of  $\text{N}_2$  was increased. A student said that an increase in the concentration of  $\text{N}_2$  would cause

the equilibrium to shift to the left. The lecturer explained that an increase in  $[N_2]$  would shift it to the left because the added  $N_2$  will be used up. More  $NH_3$  will be formed than the reactant. The lecturer asked the class to look at a catalyst. He said that it just increases the rate. He further explained that one could have a catalysed and an uncatalysed reaction. It will be lengthy under the same condition. He asked what the effect catalyst was. A student said that it would have no effect. The lecturer asked if that was clear. He told the class that question two and three displayed on the transparency was for homework. He asked what  $-92$  meant. A student said that the reverse reaction is exothermic. Another student disagreed and said that the forward reaction is exothermic and the reverse is endothermic. The lecturer said that therefore heat is a product and asked them the following question: 'once a match is burning, must you light it again? Burning wood is exothermic'. A student commented, 'so in endothermic reactions energy is a reactant. Another student commented, 'So the catalyst does not affect equilibrium'. The lecturer agreed that it had no effect and added that equilibrium is just reached quicker. A student asked whether a catalyst could slow down a reaction. The lecturer responded to the students question in a one on one discussion.

#### **Mr Moerane framing at the end of the lesson- Reflections.**

I think that the lesson went well. The introduction and examples were relevant to the standard of the learners. There is one thing I would change though. I wish I could have brought a 'ball game' to illustrate the concept of 'dynamic equilibrium' when:

- The students struggled to comprehend equal rates of the opposing process; and
- They confused constant concentrations at equilibrium with equal concentrations.

Other wise I feel I have met all the outcomes except that I misplaced the last homework questions re: calculations of  $K_c$ -values.



## **APPENDIX F: MR DHLAMINI'S PaP-eR**

This PaP-eR focuses on an interview with Mr Dhlamini in response to the questions in the interview schedule in Appendix A and Mr Dhlamini's two lessons teaching the topic, chemical equilibrium to access chemistry students.

### **PaP-eR – Chemical Equilibrium**

Mr Dhlamini was an access chemistry lecturer at the Technikon Witwatersrand. He is an expert in chemistry and was completing his PhD at a higher education institution. He does not have a teaching qualification but he has 5 years experience tutoring students in chemistry in an access programme at the institution where he is currently studying. It is the first time that he has taught chemistry in the access programme at the Technikon Witwatersrand. The interview in response to the interview schedule, the one lesson that he taught to an engineering class and one to a health sciences class has been integrated into a PaP-eR.

### **Mr Dhlamini's framing in the interview-preparation of the lesson**

#### **Planning**

In response to the question on planning, Mr Dhlamini said that he considers how he viewed the students' understanding of equilibrium. In addition to that he made sure that he prepared sufficient slides, though not too many to use in the lesson. He emphasised that the overheads were prepared in advance.

#### **Resources**

In order to prepare the lesson and the slides he used textbooks and the Internet. The textbooks that he liked to use are general chemistry textbooks.

### **Prior Knowledge**

With respect to prior knowledge, Mr Dhlamini said that he did consider the prior knowledge of the learner. He said that he was aware of the existence of misconceptions and that he had encountered them with the students that he had taught. One of the problems he identified was expressing  $K_c$  as concentration rather than as a constant.

### **Content Knowledge**

For Mr Dhlamini the order of teaching the concepts was important because students needed to understand the concept 'chemical equilibrium' before moving on to the other concepts.

### **Approach to teaching**

He said that with respect to his approach to teaching, the pace of the lesson depended on the learners' responses to what was being taught. He said that it would also be good for the students to do laboratory work while the topic was being taught so that they could have physically observed changes as a result of the equilibrium being affected.

### **Assessment activities**

Mr Dhlamini also said that the phrasing of tutorial questions relevant to the students was important.

### **Mr Dhlamini's Lessons**

After the lecturer had welcomed the students and told them that the lesson would be three periods (120 minutes), he promised that he would let them have notes at the end of the lesson. He hands out lecture notes to the students at the end of the lesson so that the students are not distracted and they participate in the lesson.

### **Introduction**

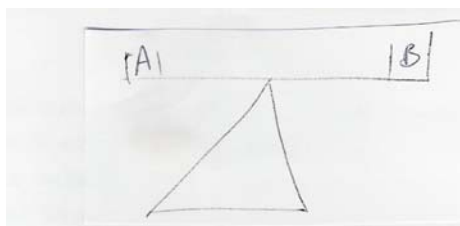
In Mr Dhlamini's approach to teaching the topic chemical equilibrium, he seemed to focus on certain concepts that he believed were important for the learners to

understand. Mr Dhlamini introduced the concept 'equilibrium' by splitting the word equilibrium into 'equi' and 'libra' and interrogating the meaning of each. He used a pair of measuring scales to discuss the meaning of libra. He then brought the meanings of the two words together again to coin the meaning of equilibrium as 'equally balanced'. He then looked at a few examples of equilibrium. One of the examples he looked at was balanced forces in physics, but highlighted that one cannot observe the counteractions as the equilibrium is static. He used phase equilibrium as an example of equilibrium and expanded on it to show the dynamic nature of equilibrium. He pointed out to the learners that when dynamic equilibrium happens in a chemical reaction, it is regarded as chemical equilibrium. After he introduced the idea of reversible reactions, he used "rate" in the context of physics to develop and then expand on the idea of "rate" in a chemical reaction.

He expanded on the concept 'dynamic' using phase equilibrium of water as an example and then he moved on to discuss the different types of systems in chemistry. He moved on to  $K_c$  and the different types of equilibrium, homogeneous and heterogeneous equilibrium. Le Chatelier's principle was introduced during the discussion on conditions of equilibrium and the factors that affect equilibrium. Finally the effect of temperature, pressure and concentration were discussed using a classroom activity.

### **The concept 'Equilibrium'**

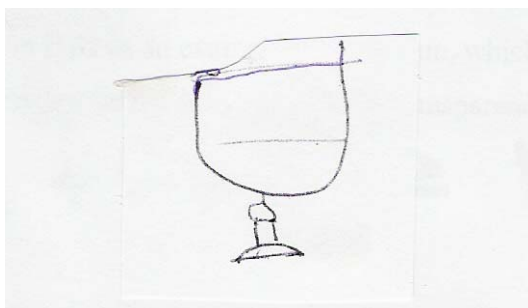
Once the lecturer had introduced his lesson, he asked the students the meaning of 'equi'. One of the students responded by saying that it means "equal". The lecturer acknowledges the response as correct and told the class that the word equidistance meant travelling from either end would be equal. He also asked the meaning of 'libra'. One of the students said that it was a star sign. He said that he was expecting this response and then used the following diagram of a scale to show that it meant a pair of measuring scales that are used to balance things or substances:



**Fig. 1: A drawing of a scale used to discuss the definition of equilibrium.**

After he drew the diagram of the scale, he said that if they know the words ‘equi’ and ‘libra’, what equilibrium means. One of the students said that it meant equally balanced. He acknowledged that it was correct and highlighted the fact that with respect to equilibrium there are two opposing processes that must be balanced or equalised. He reminded the students about many other examples of equilibrium which they had done before. The following are examples of equilibrium:

- Balanced forces where the resultant is 0. He pointed out to the students that these balanced forces were static rather than dynamic. Since they are balanced one won't see the effect of the counteractions.
- State or phase equilibrium. The following example accompanied by a diagram that was drawn on the chalkboard was used to revise the state or phase equilibrium discussed in module 1 of the syllabus: If you take a beaker and close it at the top. Fill it with water. Heat it with a bunsen burner on a hot plate. He drew the following diagram on the chalkboard to represent the beaker being heated:



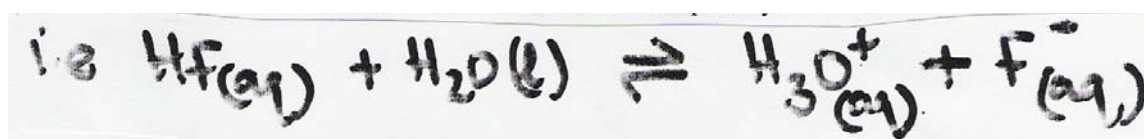
**Fig. 2: A diagram of a beaker of water being heated.**

Water evaporates forming vapour and the vapour condenses back to form water. The lecturer told the students that another example of phase equilibrium was “dry ice”, which sublimates to form carbon dioxide.

### Reversible reactions

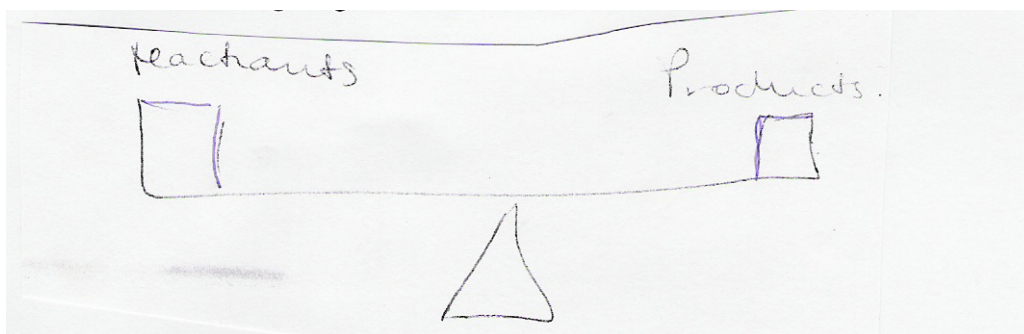
After Mr Dhlamini had discussed the concept ‘chemical equilibrium’, he asked the class what else was important and one of the students responds that it is how much time taken. He said that he liked that response. It had something to do with time. He also asked: “what is the definition of speed”? A student responded d/t. He said that time had to do with how fast the reactants and products are being formed. He said that there were some introductory concepts to aid them with their understanding. If you have reactants that react chemically to form products, on the left hand side one has the reactants and on the right hand side the products. If the reaction goes to completion, you have products and one of the reactants gets completely used up. At the end of the reaction, if you have equal amounts of reactant and product, then the reaction is reversible. If the reaction does not go to completion equilibrium will be established where the rate at which the products form is equal to the rate at which the reactants form. The lecturer reminded the students that they had already covered acids and bases and asked why HCl is a strong acid. A student said that it ionises completely in water. The lecturer explained that at the end of the reaction there was no HCl in the solution. It meant that all the reactants converted completely and are totally transformed in a reaction. A student said that there would still be some starting material. The lecturer continued without addressing the comment and said that they had already encountered weak acids and bases, which ionise partially in water. He used HF in H<sub>2</sub>O as an example of a reaction, which does not go to completion.

He showed the following ionisation reaction on a transparency:



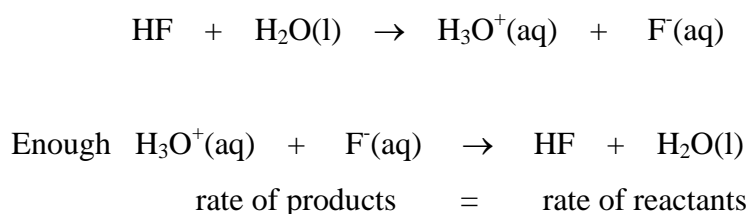
**Fig. 3: An equation showing the ionization of hydrofluoric acid.**

He told the class that although there is a point reached whereby amounts of HF and  $\text{H}_3\text{O}^+$  and  $\text{F}^-$  is constant over a given time, the reaction does not go to completion. He went back to the definition of equilibrium. One student said that it meant equally balanced. The lecturer drew the following diagram on the chalkboard:



**Fig. 4: A drawing of a scale used to discuss the definition of equilibrium.**

He told the class that reactants and products do not change with time. According to the two opposing reactions rate of forward reaction equals rate of the reverse reaction. The lecturer wrote the two half equations which represent the ionisation of HF on the chalkboard:

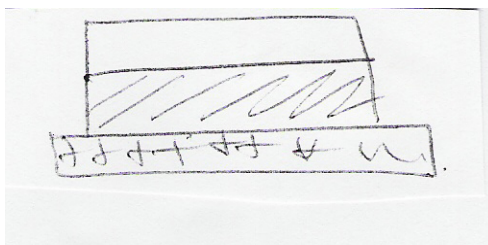


**Fig. 5: Equations showing the ionization of hydrofluoric acid.**

### **Discussion of the concept ‘dynamic’**

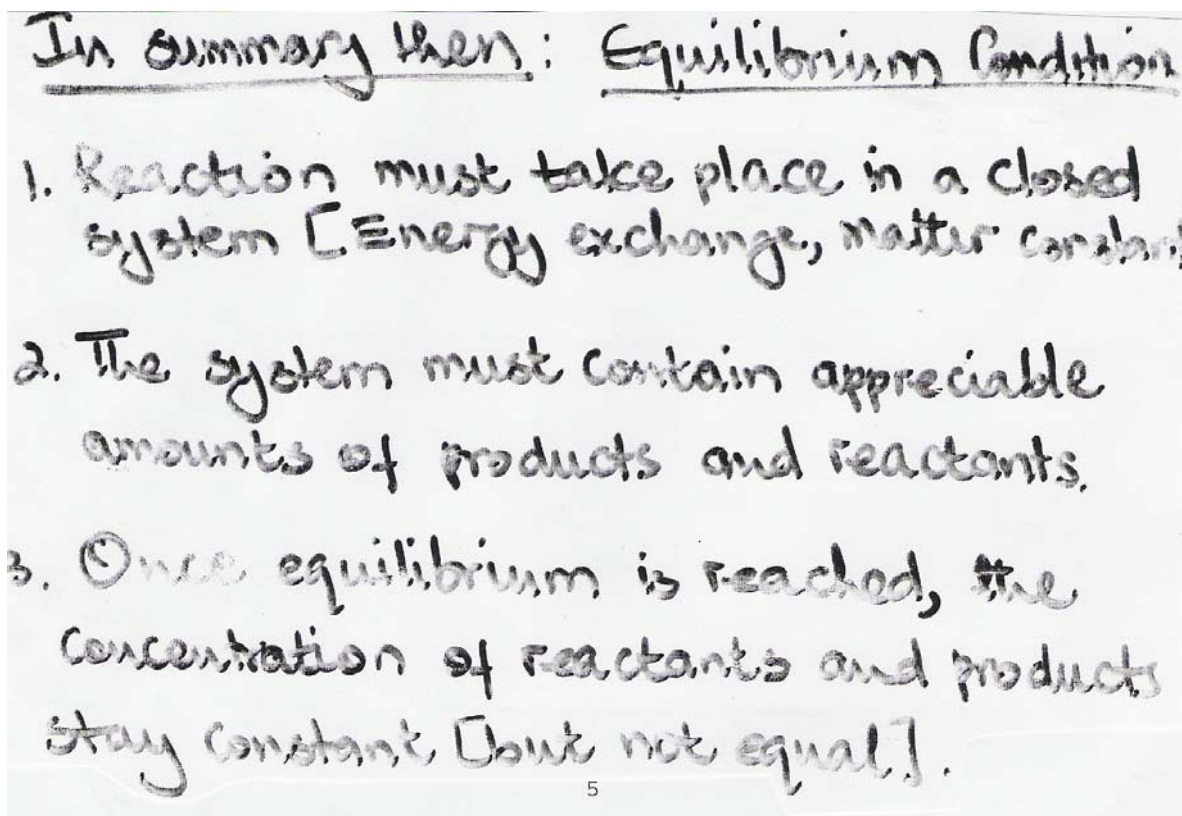
Once the idea of rate of reactions had been established, the lecturer discussed the concept ‘dynamic’. He began his discussion by telling the students that for a system to be at equilibrium there must be balancing of two opposing reactions. He

said that the one half arrow represented the forward reaction and the other half arrow represented the reverse reaction. The lecturer said that in chemistry when that equilibrium is reached, it is known as 'dynamic chemical equilibrium'. He asked what dynamic meant. A student said that it meant motion, movement. The lecturer probed further and asked what was meant when you say someone is dynamic. The student said that it meant active, energetic. The lecturer added that it meant forceful, full of energy. He used an example of phase equilibrium to explain the meaning of dynamic when it is used in conjunction with equilibrium. He said that a half-filled beaker of water must be placed on a hotplate and then drew the following diagram on the chalkboard:



**Fig. 6: Mr Dhlamini's diagram of a beaker of water being heated.**

He asked the students what would happen to the level of water in the beaker. One student asked whether it had been sealed. Another student said that the level would decrease. The lecturer agreed and said that it would evaporate. The lecturer said that once the water started condensing, after about 2 hours, it would not change. There would be no changes macroscopically. There would be dynamic equilibrium with regard to phase change. Microscopically, the reagents are converted products and vice versa. What you would notice is that there are changes at a microscopic level. The lecturer displayed the following transparency and said that there were three conditions to be met for equilibrium:



**Fig. 7: A summary of the conditions for equilibrium which were written on a transparency.**

### **Discussion of various systems**

After highlighting the conditions of equilibrium, the lecturer looked at the different types of systems. He said that there are three types of systems,

- isolated
- closed – a closed vessel so matter does not escape
- open

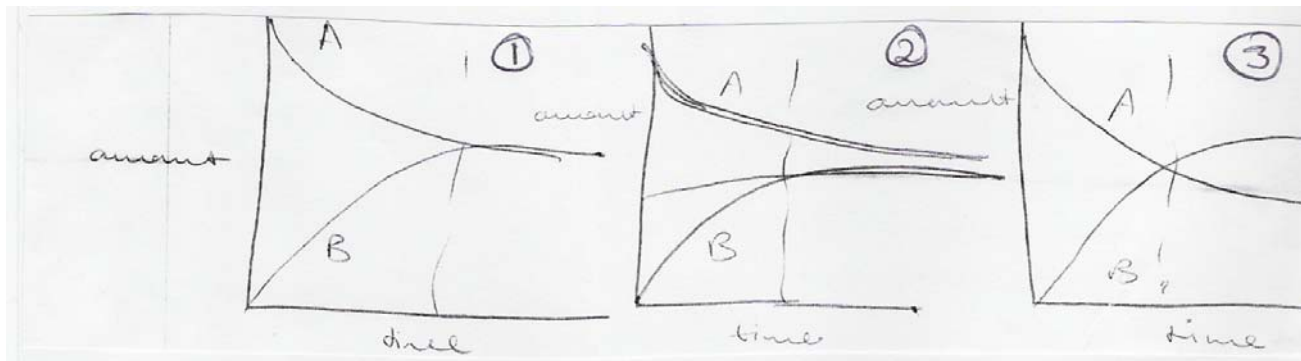


He wrote the following on the chalkboard:

<u>Systems</u>		
Isolated	Closed	Open system
Matter and energy cannot be exchanged.	Matter is not exchanged. Energy is exchanged.	Matter and energy can be exchanged.
E.g. thermos flask for hot drinks.		

**Fig. 8: Mr Dhlmini's chalkboard summary used to discuss isolated, closed and open systems.**

After break, the lecturer drew the following three graphs on the chalkboard:



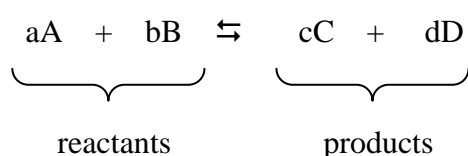
**Fig. 9: Mr Dhlamini's three graphs showing equilibrium**

He established through questioning that graphs showed chemical equilibrium had been reached because at a certain time the amounts remained constant showing that concentration was constant.

### Moving on to $K_c$

From the discussion on concentration, Mr Dhlamini discussed the concept,  $K_c$  supported by several transparencies. He asked with regard to equilibrium what the term  $K_c$  was. He said that some books refer to it as  $K_{eq}$  and the position of equilibrium.

The lecturer explained that  $K_c$  stems from the equation, which he wrote on the chalkboard:



**Fig. 10: An general equation representing a chemical reaction.**

He told the students that the  $K_c$  expression is given by:

$$[D]^d [C]^c / [A]^a [B]^b$$

**Fig. 11: The general equilibrium constant expression**

He established how to derive the equilibrium constant.

The lecturer asked a volunteer to give the  $K_c$  for reaction 1 on the transparency:

### Homogeneous and heterogeneous equilibrium

The lecturer told the class that to a point they understood the two examples. He said all the reagents and products were in the same phase. He asked what they would be called by inference. In other words what type of phase equilibrium? One of the students said that it was phase, homogeneous equilibrium. The lecturer said that the reactants and products are in the same phase. Through questioning he established homogeneous and heterogeneous equilibrium. He asked for a volunteer for the next one. A student wrote the following on the chalkboard:

$$K_c = [\text{NH}_4^+][\text{OH}^-]/[\text{NH}_3]^2[\text{H}_2\text{O}]$$

**Fig. 12: A student response showing the equilibrium expression of a reaction**

The students clapped. The lecturer said that had it been a guess, it would have been correct. He said that anything in liquid or solid phase should not be included in  $K_c$ .  $\text{H}_2\text{O}$  and liquid must be excluded. He asked who could write the expression for the dissociation of  $\text{PbCl}_2$  to form  $\text{Pb}^{2+}$  and  $\text{Cl}^-$ . Another student volunteered the following response:

$$K_c = [\text{Pb}^{2+}][\text{Cl}^-]^2$$

**Fig. 13: A student response showing the equilibrium expression of a reaction**

The lecturer told the class that ions were aqueous and that was why they were included. He asked a volunteer to write the response to the last exercise on the chalkboard. A student wrote the following answer on the chalkboard:

$$K_c = [\text{CO}_2]$$

**Fig. 14: A student response showing the equilibrium expression of a reaction.**

The lecturer said that it was not correct and that somebody must correct him. A student corrected the expression with the following:

$$K_c = 1/[\text{CO}_2]$$

**Fig. 15: A student response showing the equilibrium expression of a reaction.**

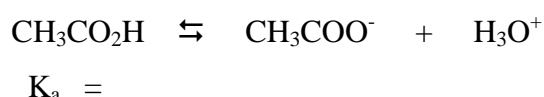
The lecturer said that the second time it was correct. He said that the students should take note that  $K_c$  is a ratio between reactants and products and wrote the following on the chalkboard:

$$K_c = \text{Prod/React} = 1/1x [\text{CO}_2]$$

**Fig. 16: A student response showing the equilibrium expression of a reaction.**

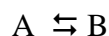
### Introduction of other aspects of $K_c$

The lecturer continued with his discussion on  $K_c$  after homogeneous and heterogeneous equilibrium. He asked the students to take note of the other word used. He said that in  $K_b$ , the b represented base. He also introduced  $K_{sp}$ , where sp represented solubility product. Lets take a weak acid, he wrote the following on the chalkboard:

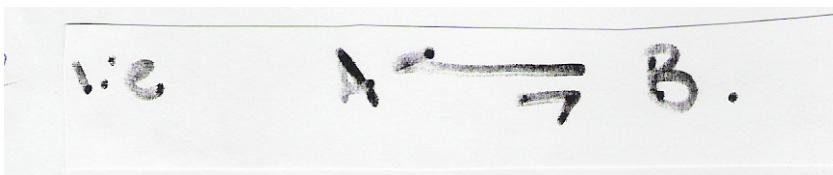


**Fig. 17: An equation representing the ionization of a weak acid.**

The lecturer said that it was critical that  $K_c$  should only include substances in gaseous and aqueous phases. Solid and liquid were not included. The lecturer said that they had looked at the first part (equilibrium constant) and were going to look at the second part (position of equilibrium). He said that position of equilibrium was just a fancy word that textbook writers used to confuse you. The lecturer said that if you had a system where

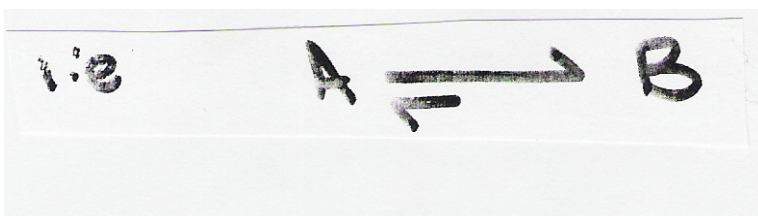


The expressed “position of equilibrium lies to the left” is textbook jargon. He said that the relative amount of A is greater than the relative amount B. For that system rather than double arrows  $\rightleftharpoons$  the following arrow:



**Fig. 18: An equation representing the equilibrium between A and B. It shows that the amount of A is greater than the amount of B.**

The position of equilibrium lies to the right, larger amount of product (B is large compared to A). The lecturer said that if he were a writer, he would use the composition of a system for those who did chemistry.



**Fig. 19: An equation representing the equilibrium between A and B showing the amount of B is greater than the amount of A.**

### Le Châtelier's Principle

He referred to Le Châtelier's principle on the transparency which bore a statement of the principle taken from a textbook.

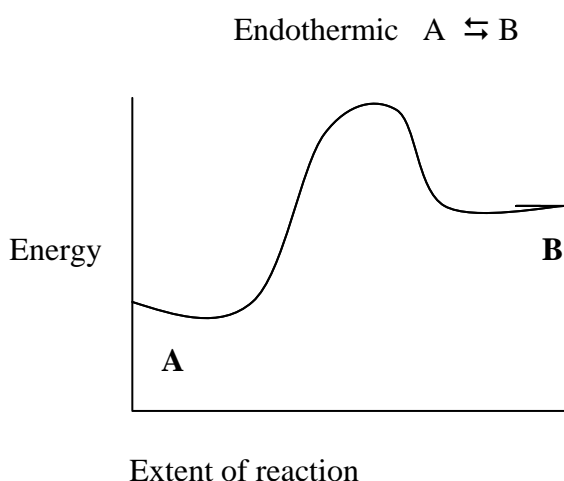
When a system at equilibrium undergoes a change of conditions, the composition of the system will change in a way that counteracts the disturbance.

**Fig. Le Châtelier's principle written on a transparency.**

He said that if you had a system at equilibrium, it would resist change. If you tried to change a system, it would counteract the changes. External changes would be counteracted. He said that they should look at the changes external to their system. He told them that the changes external to the system are temperature, pressure and concentration.

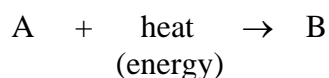
### **Effect of Change in temperature**

At this point the application of Le Châtelier's Principle, the effect of change in temperature, pressure and concentration was discussed. They looked at the first external change, which was temperature change. He said that any chemical reaction is accompanied by an energy change. He identified two types of chemical reactions, which involve energy change as endothermic and exothermic. He said that in an endothermic reaction energy is supplied for the reaction to take place. In that reaction  $\Delta H$ , enthalpy is positive. He said that it meant that the reaction must be supplied with energy for products to be formed. He represented the endothermic reaction graphically:



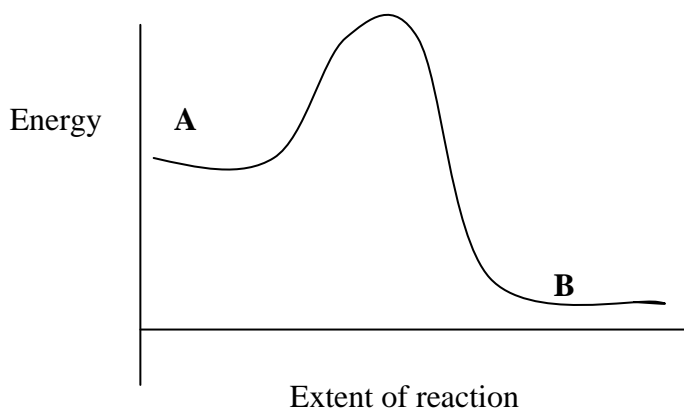
**Fig. 21: The graph representing an endothermic reaction**

He told the class that the energy content of A is lower than B. It needs energy to effect transformation. He wrote the following:



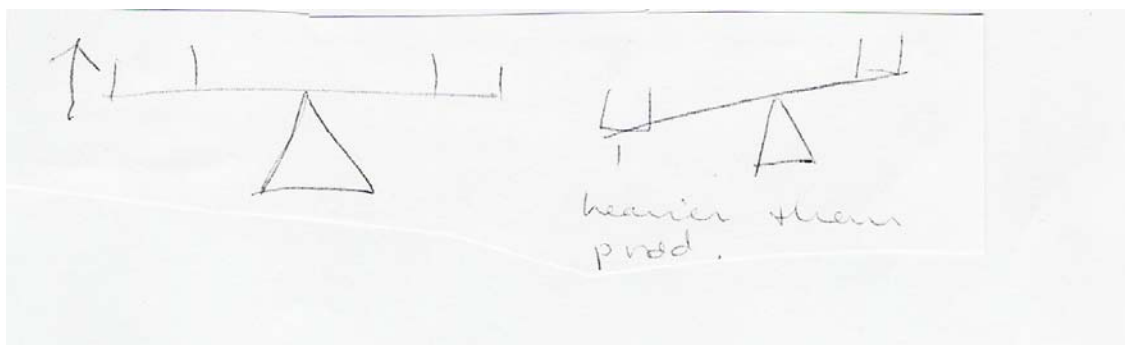
**Fig. 22: An equation representing a reaction showing the addition of heat.**

He said that in an exothermic the reactants produce products and energy. Products have less energy content than reactants. He drew a graph representing an exothermic reaction on the chalkboard:



**Fig. 23: The graph used to represent an exothermic reaction.**

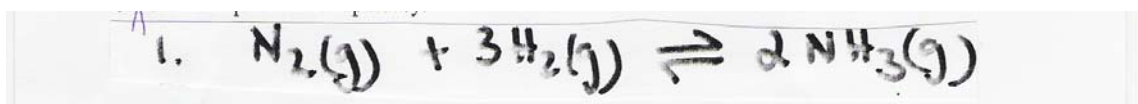
The lecturer asked how it related to the position of equilibrium. He did not want to move away from that. He asked what would happen if the temperature of the endothermic system was raised. A student said that the rate of the forward reaction would be increased. The lecturer added that it increased by forming more products. It would try to minimize it by forming more products. The lecturer draws the following equilibrium scale again:



**Fig. 24: Diagram of two scales which were used to explain the effect of temperature on equilibrium.**

He said that the disturbance was on the left hand side. The reactant side was heavier and used up more energy by forming more of the right hand side. The position of equilibrium shifts to the right, as there is an increase in energy. They looked at the exothermic reaction if the heat is increased.

A student said that it would shift to the left. The lecturer said that it was correct; the rate of reverse is greater than rate of forward. The following shows a section of a transparency with the class exercise:



**Fig. 25: The equation for example 1 of the class exercise**

A student said that it would shift to the left. The lecturer asked if it were written, where would they put heat. A student said 'right'. Lecturer filled in heat on the right hand side of the equation.



**Fig. 26: An equation used to discuss the effect of the change in temperature on equilibrium.**



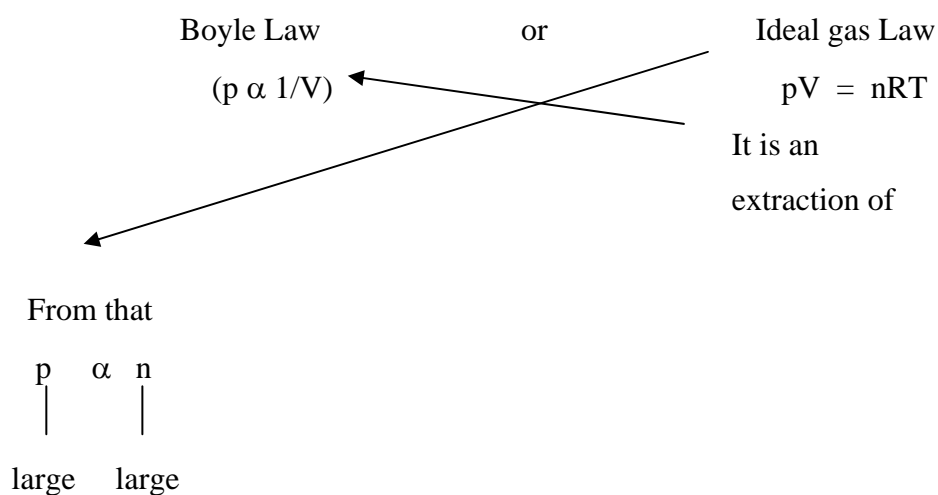
The lecturer asked what would happen to the system when you increased heat.

A Student said that the position of equilibrium lies to the left.

### **The effect of change in pressure (a discussion using Boyle's Law)**

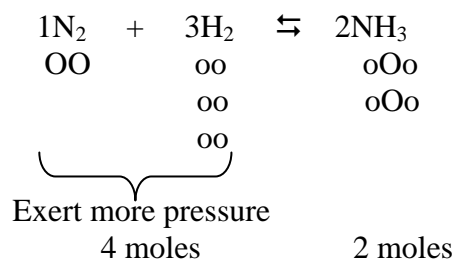
The lecturer said that the effect of pressure on a system was the same as temperature; there would be a change. He said that volume (V) and pressure (p) were linked. V and p only affected gaseous substances. Only on gas would changes have meaningful effect. Liquids are not compressible like solid, so pressure changes would have no effect. Boyle's Law or the Ideal gas Law applied.

The lecturer wrote the following on the chalkboard:



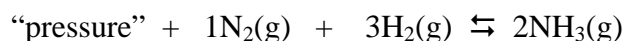
**Fig. 27: A representation used by Mr Dhlamini to discuss the effect of change in pressure.**

He said that more moles exert more pressure. A large amount of gas in a certain volume therefore has high pressure. Look at Haber process number of moles on left hand side and right hand side. Which one has more? The lecturer wrote on the chalkboard:



**Fig. 28: The equation explaining the effect of pressure on equilibrium.**

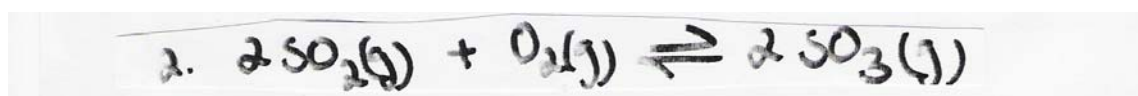
He said that they could have written pressure on the left or right hand side depending on which side had more moles of gas. He said therefore reagents exerted more pressure. He wrote pressure on the left hand side.



**Fig. 29: The equation used to explain the effect of pressure on equilibrium.**

He asked how equilibrium would be affected suppose the pressure is decreased. Will it lie to the right or left? He said that the system would adjust to the side with more pressure. It would lie to the left.

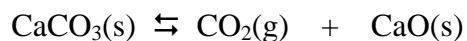
The lecturer referred to example 2 on the transparency.



**Fig. 30: The equation for example 2 of the class exercise.**

The lecturer said that he would like to see how the students would answer this question. He repeated the following: ‘An increase in pressure causes a decrease in volume and a decrease in pressure causes an increase in volume. The position of equilibrium lies to the left’. A student commented, ‘haa’. The lecturer realized that the student did not understand his explanation.

He said that from the equation they could see which side they could have written. When we decrease the volume, pressure increases. When we increase the volume, pressure decreases. It is the same argument as earlier. There was discussion amongst the students. He referred to the following example:



The lecturer asked what happens to the position of equilibrium if the pressure increases?

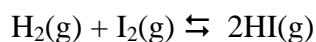
A student said that it remained the same; the only gas was on the right. The lecturer said that the pressure was on the right and gas was on the right. Products only...more pressure. What would happen if the pressure increased? A student said that the volume decreases. The lecturer said that the system would form more CaO, the equilibrium lies to the left. He asked the class to observe example 3 and asked what would happen if the pressure of the system increased. A student said that it lies to the right. The lecturer asked why. He said that they should look for the mole of gas composition. The same amount of pressure couldn't write changes on any side. An increase in pressure would therefore have no effect.

### **Effect of change in concentration**

He wrote the following on the chalkboard:

Effect of concentration

The lecturer said that he would use the same example:



**Fig. 31: An equation used to explain the effect of concentration on equilibrium.**

The lecturer read the following question off the transparency: What would have happened if more  $\text{H}_2$  were introduced to the system? He wrote the equation on the chalkboard. A student said to the right. The lecturer said that it wanted to use it up.

### The effect of a catalyst on the position of equilibrium

He said that he would not teach the common ion effect to the class. He said that a catalyst would have no effect. A catalyst is any substance which speeds up the reaction but is not consumed. It does not have any effect on the position of equilibrium.  $K_c$  is only affected by temperature changes. Any other factors will not affect the  $K_c$  value.

### Consolidation activity

This activity was done to consolidate all the concepts discussed. The class activity involved the following questions displayed on a transparency:

Class activity: For the decomposition of water vapour

$$2\text{H}_2\text{O}(\text{g}) \rightleftharpoons 2\text{H}_2(\text{g}) + \text{O}_2(\text{g}); \Delta H > 0$$

Predict the following at equilibrium.

- (a) Heating the system
- (b) Increasing the pressure of the system.
- (c) Adding more  $\text{H}_2\text{O}(\text{g})$ , volume kept constant.
- (d) Decreasing the amount of  $\text{O}_2$ .
- (e) Adding a catalyst.

Fig. 32: The Activity given to the students

Mr Dhlamini did this activity with the students.

### **Homework**

The last example was given for homework. Well that is all for today. I think we are all very tired. In the next lesson I will give you the assignment to complete.

### **Mr Dhlamini's framing at the end of the lessons**

Mr Dhlamini said that he was happy with the lesson. He said that the sequence of factual layout would remain. The duration of the lesson would change though. He would probably split the lecture into 2 half periods. He said that he would deal with  $K_c$  and allow more time (say 2 days rest) to then deal with the second aspect (position of equilibrium). He said that the section could be done after having revised the  $K_c$  section to check the level of understanding.

# **APPENDIX G: CONSENT FORM AND INFORMATION SHEET**

## **UNIVERSITY OF WITWATERSRAND**

**School of Science education**

### **MASTERS IN SCIENCE EDUCATION RESEARCH PROJECT**

#### **CONSENT FORM**

**Student Number:**.....

**Name:**.....

I have read and understood the Research Project Information sheet.

I am willing to participate in this study.

**Signed:**.....

**Date:**.....

# **UNIVERSITY OF WITWATERSRAND**

## **School of Science education**

### **MASTERS IN SCIENCE EDUCATION RESEARCH PROJECT**

Dear Access Chemistry lecturers and students

I am conducting my Masters research in the field of Science Education, in particular Chemistry Education. It focuses on Pedagogical content knowledge of the lecturer.

I would appreciate it if you would participate in this research project by completing the attached questionnaire. However, your participation is completely voluntary. If you choose to participate, whatever you say will remain confidential.

The information collected will be used anonymously and no student numbers or names will be used in any reports. None of what you say will be used against you or affect your mark in any way. All the information gathered will be used to contribute to Science Education research and for the development of Science Education.

If you have any questions, could you kindly contact me?

Thanks for your assistance. Your time and effort is appreciated and will be of value to the research.

Nadine Dharsey

## APPENDIX H: A SAMPLE OF MR MOERANE'S PLANNING DOCUMENT

Mapine

Static equilibrium  
vs  
Dynamic equilibrium

State of balance by opposing forces

rate of the forward process is equal to the rate of the reverse process.

• Rates of the opposing reactions are equal

Examples of Dynamic equilibrium in a closed system

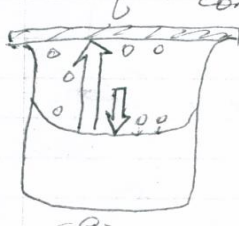
What is a closed system (Where the involved species namely reactants and products molecules remain in the container or in one reaction vessel)

Example 7

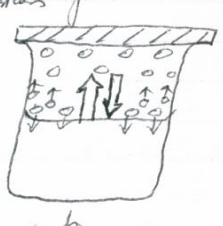
phase equilibrium is dynamic

At a particular temperature in a closed system

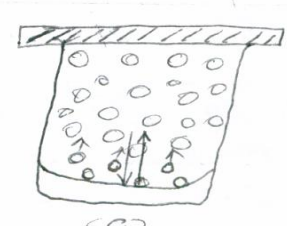
Liquid  $\xrightleftharpoons[\text{Condensation}]{\text{Vaporization}}$  Vapour



(a)  
Before reaching equilibrium



(b)  
State of equilibrium at low temperature



(c)  
State of equilibrium re-established at higher temperature



**APPENDIX I: A SAMPLE OF MR DHLAMINI  
PLANNING DOCUMENT**

the rate of forward reaction = rate of reverse reaction.

⇒ It is then referred to as dynamic equilibrium: Noticeable activity is not accompanied by observable change. Something appears to stay the same but is changing continuously (microscopically).

In summary then: Equilibrium Conditions

1. Reaction must take place in a closed system [Energy exchange, matter constant]
2. The system must contain appreciable amounts of products and reactants.
3. Once equilibrium is reached, the concentration of reactants and products stay constant [but not equal].

## APPENDIX J: ACCESS CHEMISTRY MATERIAL

### CHEMICAL EQUILIBRIUM MODULE

#### MODULE 6

#### Chemical equilibrium

##### Learning outcomes:

At the end of this module the learner must be able to:

- State the criteria that must be met for a system to be in equilibrium and relate to the concept of dynamic equilibrium.
- State and apply Le Chatelier's principle to homogeneous gas phase equilibria only.
- Explain what an exothermic and endothermic reaction is using heat as a reagent or a product of the reaction.
- Identify the relevant factors included in an equilibrium constant.

##### *DYNAMIC EQUILIBRIUM*

In some chemical reactions all the reactant molecules are completely transformed to product molecules. These reactions **go to completion**.

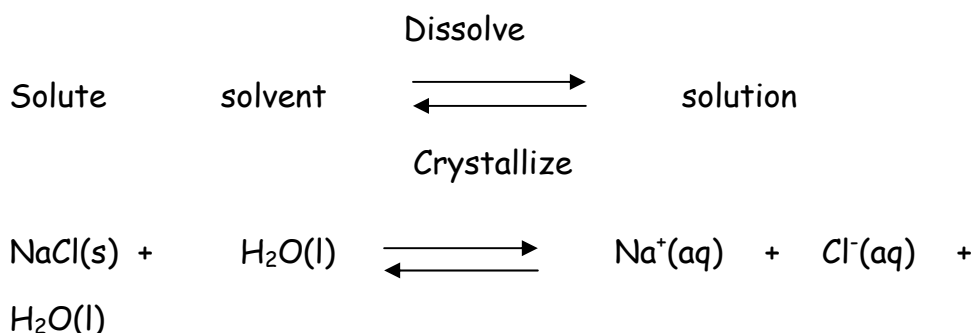
Some reactions don't go to completion even though unused reactant molecules remain in the solution. Not all the reactants are converted to products; an **equilibrium** is reached.

For example: A closed container that contains  $\text{N}_2(\text{g})$  and  $\text{H}_2(\text{g})$  which reacts to form  $\text{NH}_3(\text{g})$ .

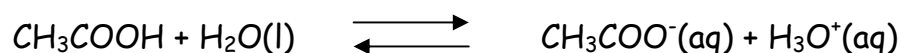


- **Equilibrium conditions:**
  - Reaction in a closed system (the reactant and product molecules must remain in the system)
  - The system contains appreciable concentrations of both reactants and products, and

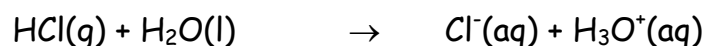
- The attainment of equilibrium might be slow, but once it has been achieved, the concentrations of all the participating species stay constant (but not equal).
- **System in equilibrium:**
  - Rate at which the reactant molecules form product molecules  
= rate at which product molecules form reactant molecules.
  - This is called **dynamic equilibrium**: something appears to stay the same, but is changing continuously.
  - A **saturated solution** is a solution that is in equilibrium with the undissolved solute.
  - EXAMPLE:
    - A *saturated solution* of NaCl:



- A *weak acid* is in equilibrium with its ions:



- But a strong acid dissociates completely (NO EQUILIBRIUM!):



## THE EQUILIBRIUM CONSTANT

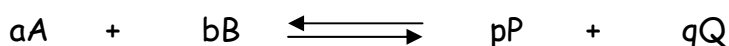
At equilibrium:

$$\begin{array}{ccc} \text{Rate(reactant} \rightarrow \text{product)} & = & \text{rate(product} \rightarrow \text{reactant)} \\ \text{(forward reaction)} & & \text{(reverse reaction)} \end{array}$$

and

- The processes don't stop, they react at the same rate
- Equilibrium can be reached from both directions

If we have a balanced equation, where



- A, B, P and Q are the reactants and products
- a, b, p and q are the coefficients in the balanced chemical equation

Then  $K_c$  = equilibrium constant  
= mathematical relationship connecting the concentrations of the participating species in equilibrium

$$= \frac{[P]^p \times [Q]^q}{[A]^a \times [B]^b}$$

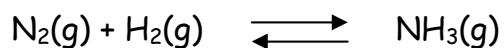
$K_c$

- does not depend on the starting concentrations (if there is less reactants, the products will be less)
- does not depend on other substances in the solution that do not participate in the reaction (e.g. catalysts)

- does vary with a change in temperature
- has no units
- EXAMPLE:

A mixture of  $\text{H}_2$  and  $\text{N}_2$  in a reaction vessel is allowed to attain equilibrium at  $472^\circ\text{C}$ . The equilibrium mixture of gases was analyzed and found to contain  $0.1207\text{M}$   $\text{H}_2$ ,  $0.0402\text{M}$   $\text{N}_2$  and  $0.00272\text{M}$   $\text{NH}_3$ . Calculate  $K_c$ .

Step 1: Write the balanced equation



Step 2: Write the formula for  $K_c$  and calculate

$$\begin{aligned} K_c &= \frac{[\text{NH}_3]^2}{[\text{N}_2] \times [\text{H}_2]^3} \\ &= \frac{(0.00272)^2}{(0.0402)(0.1207)^3} \\ &= 0.105 \end{aligned}$$

- if  $K_c \gg 1$ , the equilibrium lies to the right, favoring the formation of products
- if  $K_c \ll 1$ , the equilibrium lies to the left, favoring the formation of reactants

THUS, the equilibrium for the formation of  $\text{NH}_3$  at a temperature of  $472^\circ\text{C}$  favors the reverse reaction.

- for  $\text{A} \rightleftharpoons \text{B}$ ,  $K_c = \frac{[\text{B}]}{[\text{A}]}$

- for  $B \rightleftharpoons A$  ,  $\frac{1}{K_c} = \frac{[A]}{[B]}$

EXAMPLE:

For the formation of  $\text{NH}_3$  from  $\text{N}_2$  and  $\text{H}_2$ ,  $K_c = 4.34 \times 10^{-3}$  at  $300^\circ\text{C}$ .

What is the value of  $K_c$  for the reverse reaction?

Step 1: Write the equation for  $K_c$  (forward reaction)

$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2] \times [\text{H}_2]^3} = 4.34 \times 10^{-3}$$

Step 2: Write the equation for the reverse reaction.

$$\frac{1}{K_c} = \frac{[\text{N}_2] \times [\text{H}_2]^3}{[\text{NH}_3]^2} = \frac{1}{4.34 \times 10^{-3}} = 2.30 \times 10^2$$

### ***LE CHATELIER'S PRINCIPLE***

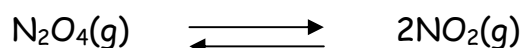
**Definition:** If a system is in equilibrium and some factor in the equilibrium conditions is altered, the composition of the system will change in a way that counteracts the disturbance.

Thus, the equilibrium is in a state of balance. When the conditions change, the balance is disturbed. The equilibrium will shift in the

direction that will minimize the effect of the change, to obtain a new state of balance.

- **Effect of a change in pressure:**

EXAMPLE:



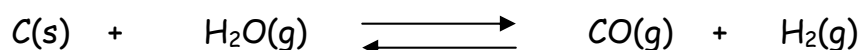
- If we increase the pressure (by decreasing the volume), Le Chatelier says that the concentrations of  $\text{N}_2\text{O}_4$  and  $\text{NO}_2$  will change to counteract the change in pressure.
- For every 1 molecule of  $\text{N}_2\text{O}_4$ , there is 2 molecules of  $\text{NO}_2$ . 1 molecule will take up less space than 2, so a decrease in the total amount of gas molecules will reduce the pressure at the new volume.
- The equilibrium will shift to the left, favoring the reverse reaction.
- If an equilibrium reaction does not involve a change in the number of molecules in the ***gaseous phase***, the changing the pressure will not effect the composition of the equilibrium mixture (concentrations).

EXAMPLE:



Each side has 2 molecules, so a change in pressure has no influence.

- With mixtures of solids and gases, e.g.



The volume of the solid is so small compared to that of the gases, we need not consider it. Thus, with an increase of

pressure on the above system, the equilibrium will shift to the left (least amount of gas molecules).

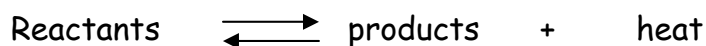
- With a decrease in pressure, the opposite will happen in order to compensate.

- ***Effect of change in temperature:***

- **Endothermic reactions:** The reaction absorbs heat in order to take place



- **Exothermic reactions:** the reaction produces heat with the formation of products.



- With an increase in temperature, Le Chatelier's principle states that the composition of the mixture will change to accommodate this change, so
- The equilibrium will shift in the direction that absorbs heat.

- **EXAMPLE:**



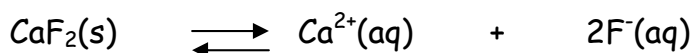
- Heat is required to produce  $\text{NO}_2$ .
- With an increase in temperature the equilibrium will shift to the right in order to use up the excess heat.
- The concentration of  $\text{NO}_2$  will increase.
- Cooling has the opposite effect.



- ***Adding a reactant or product (common-ion effect):***

- If a system is in equilibrium and the concentrations of either 1 of the reactants or products are increased, the system is disturbed.
- If the concentration of the products is increased, the equilibrium will shift to form more reactants.
- If the concentration of the reactants is increased the equilibrium will shift to produce more products. Thus, the added substance is consumed.
- With the removal of one of the substances, the equilibrium will shift to produce more of the removed substance.
- **EXAMPLE:**

The solubility of a slightly soluble salt is decreased by adding a second solute that contains a common ion:



- $\text{CaF}_2$  is slightly soluble
- If we add NaF to the solution,



all the NaF will dissociate into its ions (reaction goes to completion).

- $\text{F}^{-}$  will thus be added to the equilibrium mixture, which forces the equilibrium to the left in order to compensate.

- ***Adding a catalyst:***

- This has **no** effect on the composition of the equilibrium mixture.
- Catalysts are only used to increase the rate of the reaction, thus
  - to achieve the equilibrium state more rapidly
  - it has no effect on  $K_c$ .

**ASSIGNMENT:**

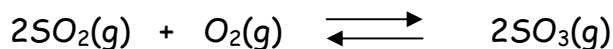
1. The dissolution of aluminium chloride in water can be illustrated by the following equation:



The solubility product ( $K_c$  for the dissolution of a salt),  $K_{sp}$ , can be given as:

- A.  $\frac{[\text{AlCl}_3]}{[\text{Al}^{3+}] \times [\text{Cl}^{-}]^3}$
- B.  $\frac{[\text{Al}^{3+}] \times 3[\text{Cl}^{-}]}{[\text{AlCl}_3]}$
- C.  $\frac{[\text{Al}^{3+}] \times [\text{Cl}^{-}]^3}{[\text{AlCl}_3]}$
- D.  $[\text{Al}^{3+}] \times [\text{Cl}^{-}]^3$

2. Consider the following chemical equilibrium in which the formation of products is exothermic:



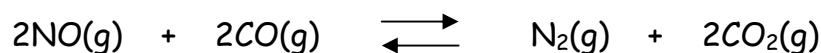
To increase the yield of  $\text{SO}_3(\text{g})$ , the system could be adjusted by

- A. decreasing the pressure on the system.  
B. Removing some of the  $\text{SO}_2(\text{g})$ .  
C. Cooling the reaction.  
D. Adding a catalyst.

3. Le Chatelier stated that

- A.  $K_c$  is the equilibrium constant.
- B.  $1/K_c$  is used to calculate the value of the equilibrium constant for an equilibrium favouring the reagents.
- C.  $K_w$  is the equilibrium constant for the self-ionisation of water and has a value of  $1 \times 10^{-14}$ .
- D. If a system in equilibrium is disturbed, it will counteract the disturbance and establish a new equilibrium.

4. Consider the following reaction system at equilibrium:



(endothermic)

The conditions that will favour conversion of reactants to products the least are

- A. low temperature and high pressure
- B. high temperature and high pressure
- C. high temperature and low pressure
- D. low temperature and low pressure

## APPENDIX K: SAMPLE OF THE ASSIGNMENT ON CHEMICAL EQUILIBRIUM

### Chemical equilibrium assignment, August 2004

#### Multiple choice questions

1. For the heterogeneous reaction,



the equilibrium constant expression for K ( $K_c$ ) is which of the following? (2)

- (a)  $K = 1/[\text{O}_2]$
- (b)  $K = k[\text{MnO}_2]$
- (c)  $K = ([\text{MnO}][\text{O}_2])/[\text{MnO}_2]$
- (d)  $K = [\text{MnO}_2]/([\text{MnO}][\text{O}_2])$
- (e)  $K = [\text{O}_2]$

2. Equilibria involving species in more than one phase are called? (2)

- (a) Heterogeneous equilibria
- (b) Homogeneous equilibria
- (c) Reversible reaction
- (d) Chemical equilibria

3. When a reaction reaches equilibrium (2)

- (a) all reaction stops
- (b) the rate of the reverse reaction is zero
- (c) the rate of forward reaction is zero
- (d) the forward and reverse reaction rates are equal
- (e) the rate of the forward reaction and the rate of the reverse reaction are equal to zero

4. Assume that the following reaction has come to equilibrium. If now the pressure is increased, one would predict that? (3)



- (a) the amounts of both reactant and product will remain unchanged but both the forward and reverse reactions will be accelerated
- (b) the system will react to increase the concentration of  $\text{NO}_2$
- (c) a prediction cannot be made without knowing whether the reaction is exothermic or endothermic
- (d) the amounts of both reactant and product will remain unchanged but both the forward and reverse reactions will be slowed
- (e) the system will react to increase the concentration of  $\text{N}_2\text{O}_4$

## APPENDIX L: MR MOERANE'S REFLECTION

### Reflection On the lesson

- \* Introduction and examples were relevant to the Standard of the learners
- \* To explain the concept 'dynamic equilibrium' where students struggled with equal rates to comprehend equal rates of the opposing process, when they confused constant concentrations @ equilibrium with equal concentrations; I wished I could have brought a 'ball game' to illustrate the concept.
- \* Otherwise I feel I have met all the outcomes except that I misplaced the last homework questions re: Calculations of  $K_c$ -Values.

## APPENDIX M: MR DHLAMINI'S REFLECTIONS

### Reflection on the lecture

The sequence of factual layout would ~~be~~ remain. Changes: probably split the lecture into 2 half, deal with  $K_c$  and allow more time (say 2 days rest) to then deal with the second aspect (Position of equilibrium). The section could be done after having revised the  $K_c$  section to check level of understanding.



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